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3 SOLAR INTERPLANETARY STUDY 4

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SOLAR INTERPLANETARY STUDY

INTRODUCTION

This is the final report of the Solar Interplanetary Study. The ensuing paragraphs review the contents of previous quarterly reports, present graphs of flare index, summarize the material on the proton flare period of July 1966, discuss the prospects for publication, and close by listing some supplementary figures of working quantities graphed as part of the study.

The main thrust of the final report period was centered around attendance at the Proton Flare Project symposium held 28, 29 July in London as part of this year's COSPAR meeting. It was clear by early July that it would be impossible for Ames to supply additional Explorer 33 magnetometer data to allow expansion of the statistical picture of field-magnetic index correlation to a publishable result, let alone to justify examination of more subtle correlations than that presented by the index. An effort was therefore made to acquire enough data on the proton flare period to yield substance of a less superficial nature, by contacting directly the solar experts participating in the PFP and by examining the data presented by them.

A paper presented at the PFP covering some of the data obtained by Explorer 33's second magnetometer (Ness and Taylor, 1967), confirmed the expectation that it was too late for putting together a superficial summary of the observations and that somewhat deeper research will be required to produce a publishable document. Efforts made in this direction are described in the report.

TOPICS COVERED BY QUARTERLY REPORTS

The following list reviews breifly the material presented in the quarterly reports, for convenient reference. The reports are designated 1, 2, 3, and 4.

FLARE INDEX

Figures 1 through 7 display a three-hour version of the index of flare activity described by Sawyer (1967). The graphs cover the six months of the second half of 1966, July through December. They are plotted on a linear scale designed to emphasize large events and suppress the general flare background activity.

Figures 8 through 14 again show the flare index, but this time on an expanded linear scale which takes the large events off scale at the top, but better exhibits the rise and fall of the general background activity level.

Comparison of the July 66 flare index with Explorer 33 field magnitude (3rd quarterly, Fig. 10) allowing a standard two-day, sun-earth delay, shows that Fig. 1 provides a better qualitative correlation than Fig. 8, making the prospects for correlation hopeful and corroborating, to some extent, the results of Greenstadt and Moreton (1962). The unknown and variable delay times which apply, however, make the accumulation of additional statistics necessary before a definitive result can be pronounced. This is discussed further in a later section.

THE PROTON FLARE SYMPOSIUM

The first symposium on the 1966 Proton Flare Project, held as part of this year's COSPAR meeting in London, on 27-28 July, demonstrated the great value of studying intensively a single event with wide coverage, continuous observation, and diverse instrumentation. Information relevant to the Explorer 33 magnetometer measurements, to the subject contract of this and previous reports, and to the associated joint Ames-TRW study, include detailed solar photospheric and chromospheric observations and concurrent measurements by particle detectors from satellites and balloons. Of particular interest were:

1. Friedman's superimposed ground and satellite eclipse photos showing a coronal streamer, and, by implication, the corotation zone, extending to 15 $R_{\odot}$ (actually, an IQSY result);

2. Mustel's denial of the existence of a general solar dipole field, which he replaced by individual flux tubes;

3. Saverny's beautiful diagrams of electric current systems in activity centers;

4. Lin, Kahler, and Roelof's (1967) observations of proton and electron flux;

5. Lazarus' report describing solar wind velocities during the proton flare interval;

6. Taylor's account of simultaneous interplanetary magnetic field observations by Explorers 28, 33, and Pioneer 6 (<u>Ness and Taylor</u>, 1967);

7. Pfotzer's analysis of high latitude balloon proton observations (<u>Heristchi</u> <u>et</u> <u>al</u>., 1967).

Some of the material presented was documented in preprint form, but most was not. Duplicates of two preprints which may not be readilv obtainable are attached to this report. One of them summarizes the birth and development of region 8362.

The cooperation of Mrs. Helen Dodson Prince of McMach Hulbert Observatory and of Mme. Pick of Meudon was sought in trying to locate the source both of individual events in the Explorer 33 July 66 data and of the general difference in background level of the interplanetary field between early and late July. Discussions with the above named at the PFP meeting were followed up by letters and, in the case of Mrs. Prince, also by telephone. In addition, a request was made of Lazarus for copies of the figures shown on his slides, and he agreed to send them. At the time this is written, Lazarus' reply has not been received. Mme. Pick has responded by letter, sending a chart of 3 cm solar emission for July 66 and a list of minor flares observed in region 8408, which she feels may be responsible for the enhanced activity of late July. No final evaluation of this material has been made yet.

The response of Mrs. Prince, in a long telephone conversation, was a stiff dose of skepticism, which I do not entirely share, for the prospects of correlating individual interplanetary disturbances with individual solar features, and little encouragement at all of any hope for quantitative correlation of field magnitudes, especially in view of the small statistic represented by the Explorer 33 graph of July data only. It was the opinion of Mrs. Prince, however, as with Mme Pick, that enhanced solar activity after 21 July, particularly in region 8408, must have been responsible for the comparative increase in the interplanetary field's base level at about the same time, and that the apparent widespread increase in mottling of the sun by photospheric magnetic field regions, shown in Howard's Mt. Wilson magnetograms, was not an effect of Mt. Wilson's seeing conditions, but represents a real phenomenon on the sun.

The above information, together with that of the Fraunhofer solar maps and the data to be provided by Lazarus, will be combined with the Mt. Wilson diagrams in the near future to yield, it is hoped, a more sanguine prospect of correlation than that anticipated by Mrs. Prince.

FUTURE PROSPECTS

The joint study of solar interplanetary phenomena, to which resources of both Ames and TRW have been contributed, has as its aim the publication of research results. Topics which may be regarded as capable of providing reports suitable for publication are:

1. Overall, largely qualitative, comparison of interplanetary field, planetary index, and solar parameters, including vector field characteristics such as ecliptic orientation of storm fields.

2. Statistical structure of the interplanetary field samples over various synoptic (averaging) time intervals.

3. Detailed behavior of interplanetary field during the July 7-10 period, including elapsed-time studies between Explorer 33, Vela 3A and B, and the earth's surface.

4. General search for origin of interplanetary field effects in specific solar features.

5. Direct test of Krimigis solar proton diffusion model by examination of interplanetary field irregularities.

The first two items above are straightforward and the basic groundwork for them is complete, some of it having been included in the 3rd Quarterly or given to Ames separately as slides for the April AGU meeting. The only requirements for a publishable report are an extension of the graphs to at least two more months of interplanetary data, together with graphs of the vector components, and the disregard or delay of the Goddard magnetometer group in reporting the same thing. Additional percentile data for December and January have been requested from Ames.

The third item requires graphs of Explorer 33's individual measurement points for the period mentioned, which have also been requested from Ames.

Item 4 requires plasma velocities and, possibly, data covering more than just July 1966. A pilot examination of this topic is underway.

The subject of item 5 should be readily accessible to study, beginning with the intensive particle measurements of 7-10 July 66 and the data requested for item 3.

CONCLUDING REMARKS

The sun, in early July 1966, tilted its north pole 2° toward the earth so that the earth's subsolar point was at heliographic latitude + 2°. The active centers in July were at heliographic latitudes either between 15 and 40°N or below 20°S. The major center, McMath 8362, responsible for the July 7-9 events was at 34°N. That the proton flare of 7 July in 8362 produced effects at the earth is accepted by solar-terrestrial experts. If we assume "plagicentric" radial emission of both enhanced non-transient and flare plasma symmetrically distributed around the heliocentric locus of 8362, then we must accept an effective latitudinal beam half-width at the earth of at least 32°. Since most centers during July were no farther from the sun's equator than 8362, and many were closer, including the very few in the southern hemisphere, we should not be surprised if the interplanetary medium sampled by Explorer 33 exhibited the influence of most activity centers, or most magnetic emission regions, whatever they might be. If the solar emission responsible for interplanetary magnetic transients is not plagicentrically radial, or is asymmetric, then the pattern of events witnessed by Explorer 33, or any other probe near the earth, will not yield one-to-one correlations and will be difficult to analyze, although, with careful attention to solar features, may yield some qualitative information on solar emission.

The key to unlocking detailed information linking specific solar features to interplanetary magnetic effects is solar wind velocity, which must be used to estimate the approximate time at which effective corotation ceased and solar wind expansion began. Whether or not a significant solar feature is to be found under the locus corresponding to the appropriate expansion point will depend on whether the time for thermal plasma, or conductive effects, to rise to the point from the chromosphere exceeds the lifetime of the associated feature. At any rate, it appears now as if it will be some time before the problem of quantitative solar-interplanetary correlation is finally resolved. It is hoped that the material still to be received from Ames, MIT, Lockheed, and other sources, and the evaluation of this material, along with that supplied by Meudon, McMath, Mt. Wilson, and the literature of concurrent satellite and ground observations, will yield some concrete new information on the distant magnetic effects of solar plages, prominences, and flares.

SUPPLEMENTARY FIGURES

The following working graphs are included with this report to complete the Explorer 33 material used in this study.

Figure 15. Some statistical characteristics of the three-hour accumulation of interplanetary field data.

Figure 16. Three-hour synoptic vector behavior of interplanetary field data.

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Greenstadt, E. W., and G. E. Moreton, A comparison of solar flare incidence with magnetic transients observed in the near-by interplanetary region by Pioneer 5, J. Geophys. Res., 67, 3299-3316, 1962.

Heristchi, Dj., J. Kangas, G. Krenser, J. P. Legrand, P. Masse, M. Palous, G. Pfatzer, W. Riedler, K. Wilhelm, Balloon measurements of solar protons in northern Scandinavia on July 7, 1966, SPARMO Report, 1967.

Lin, R. P., S. W. Kahler, and E. C. Roelof, Solar flare injection and propagation of 0.5 - 20 Mev protons and $\geq$ 45 keV electrons deduced from large spatial flux gradients observed on 7-9 July 1966, Space Sciences Laboratory, University of California, Berkeley.

Ness, N. F., and H. E. Taylor, Observations of the interplanetary magnetic field July 4-12, 1966, NASA/GSFC Report X-612-67-345, 1967.

Sawyer, C. B., Apparent area as a basis for solar flare importance, J. Geophys. Res., 72, 385-391, 1967.

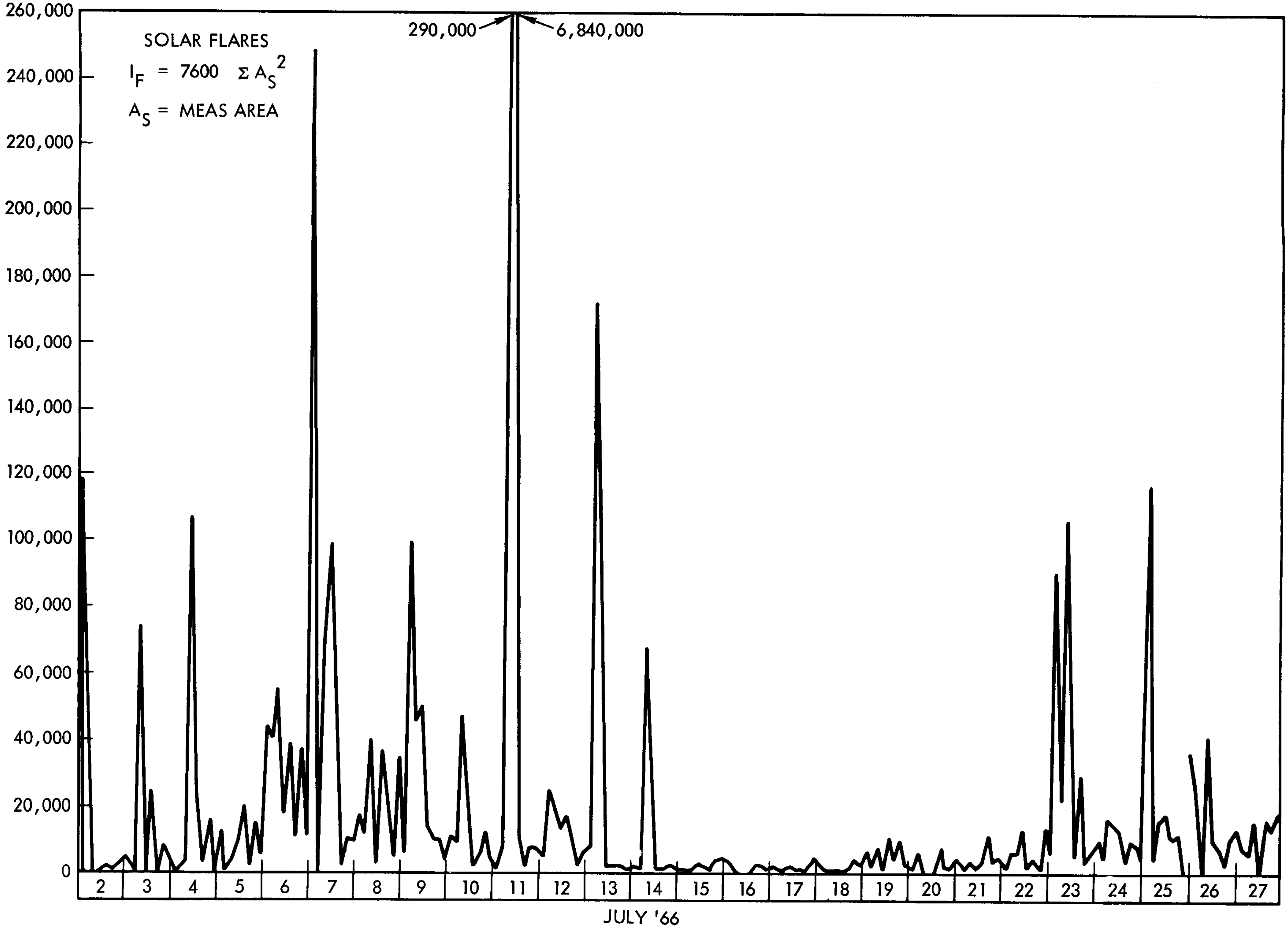


Figure 1. Solar flare index emphasizing large events.

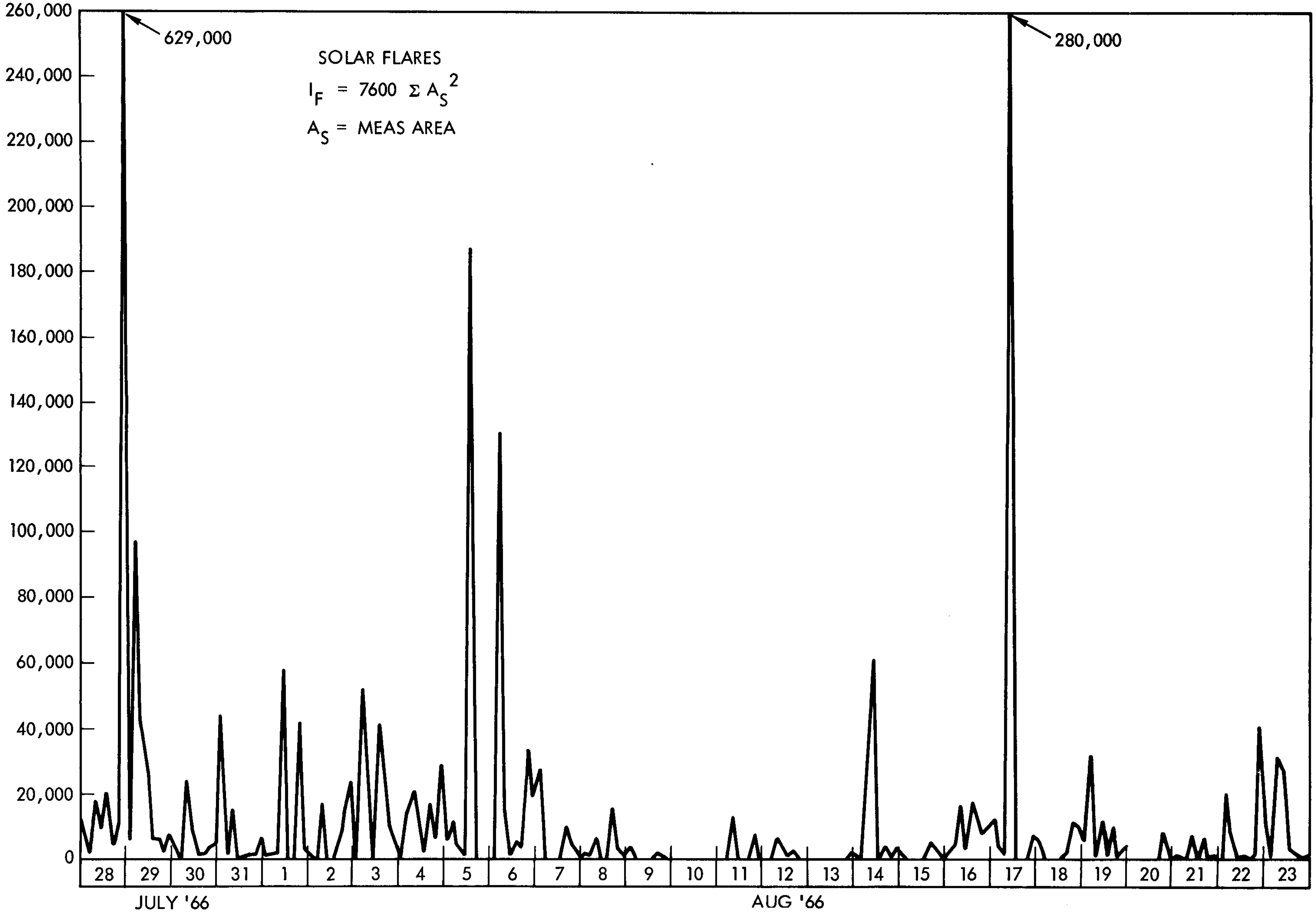


Figure 2. Solar flare index emphasizing large events.

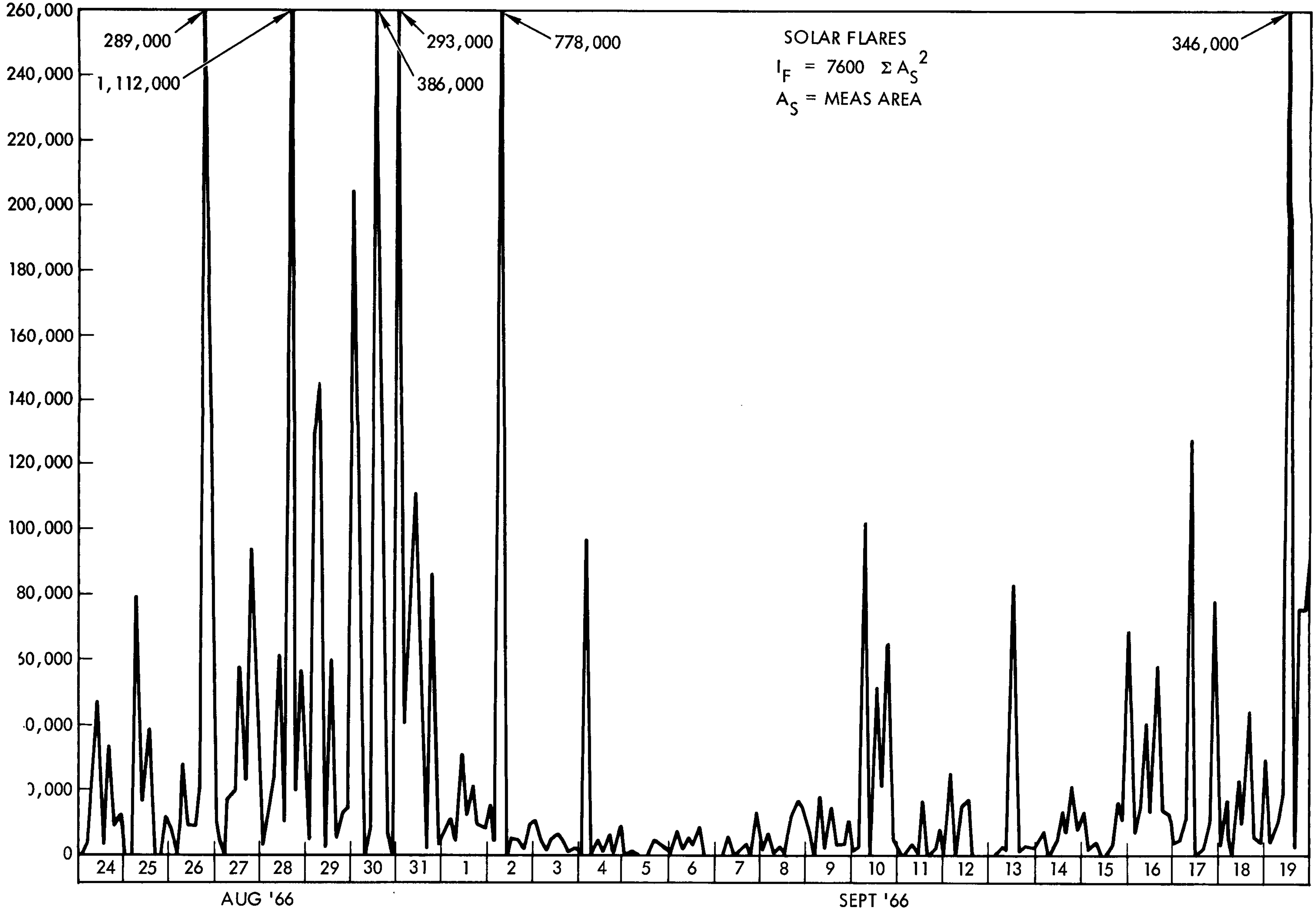


Figure 3. Solar flare index emphasizing large events.

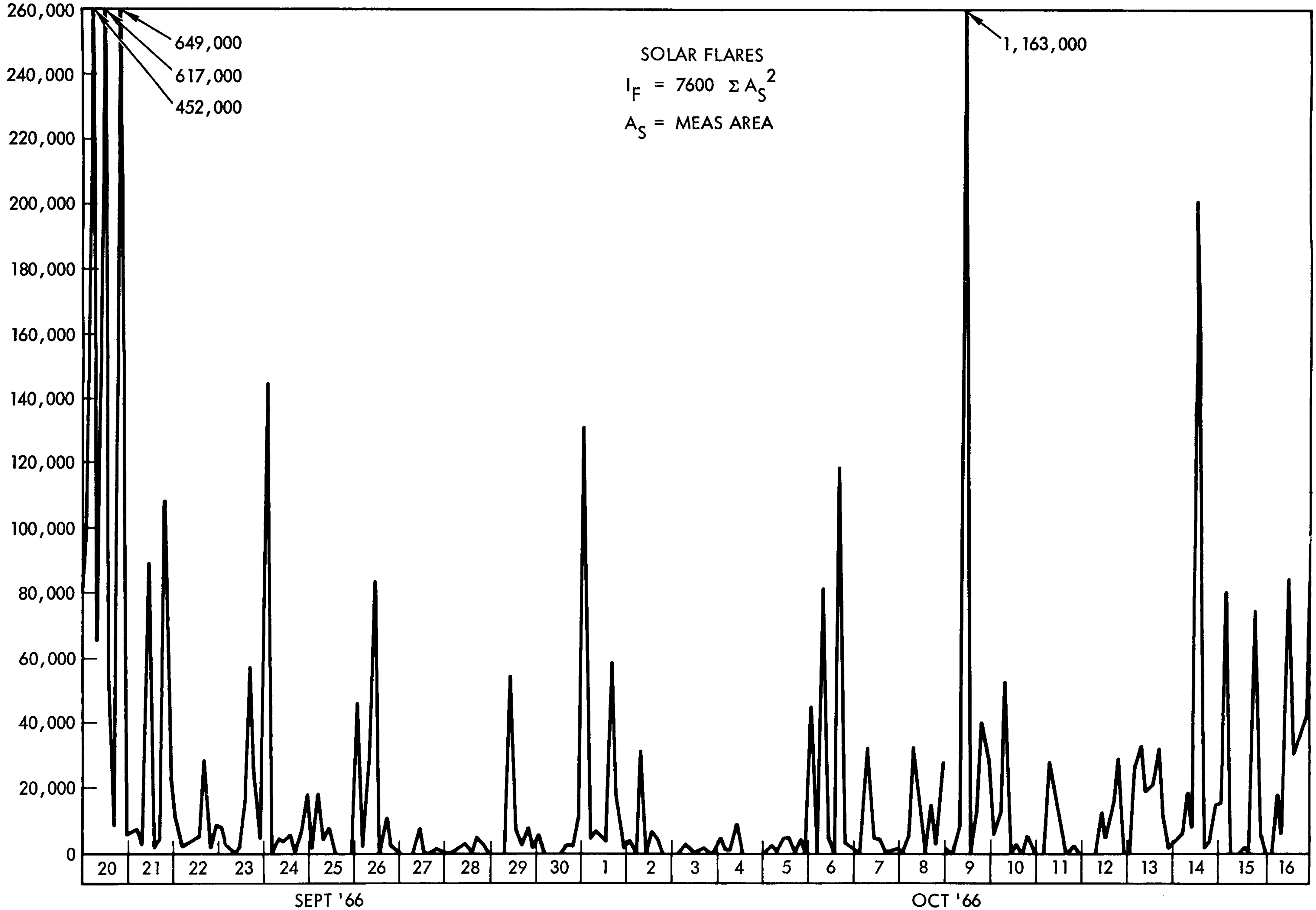


Figure 4. Solar flare index emphasizing large events.

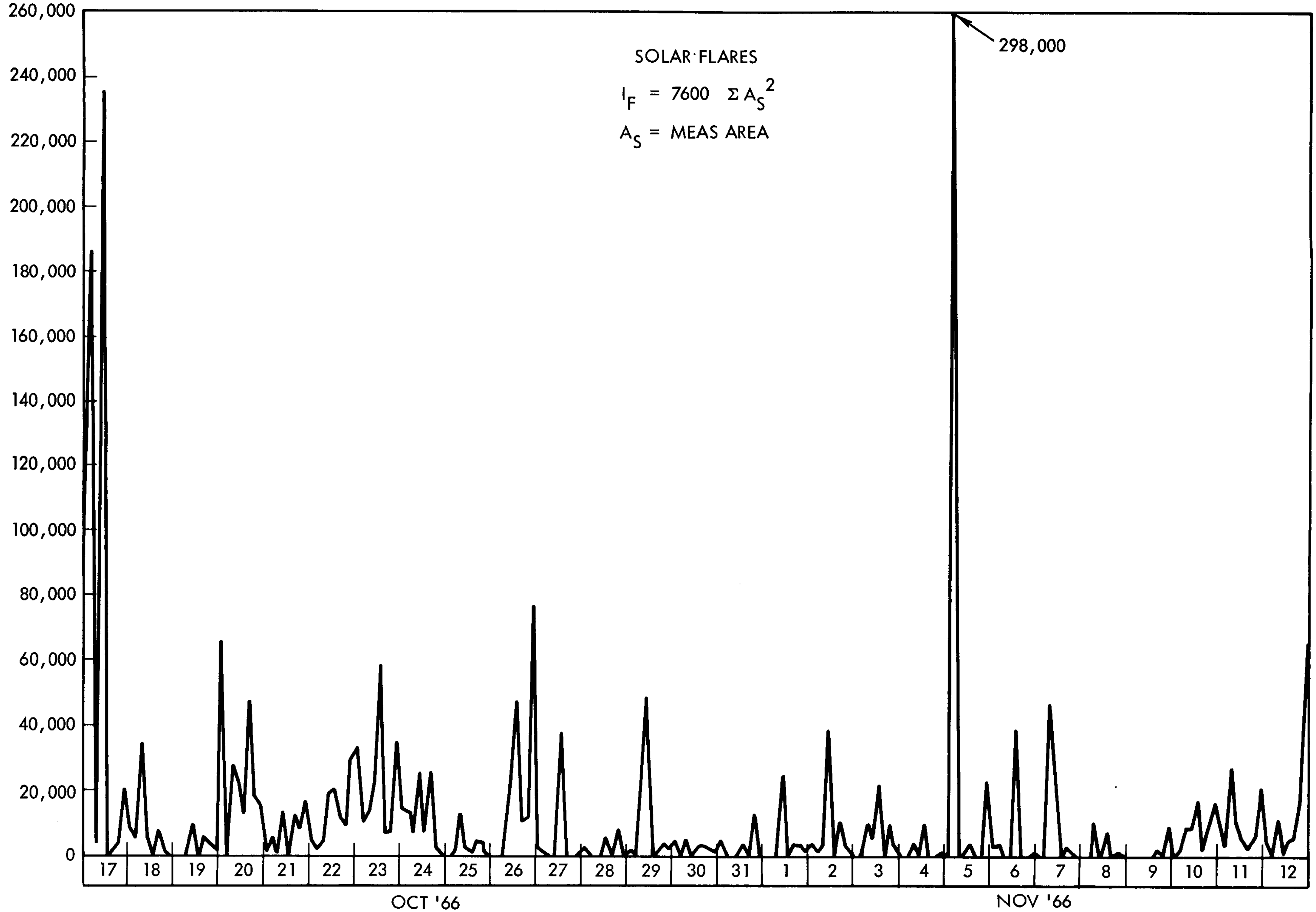


Figure 5. Solar flare index emphasizing large events.

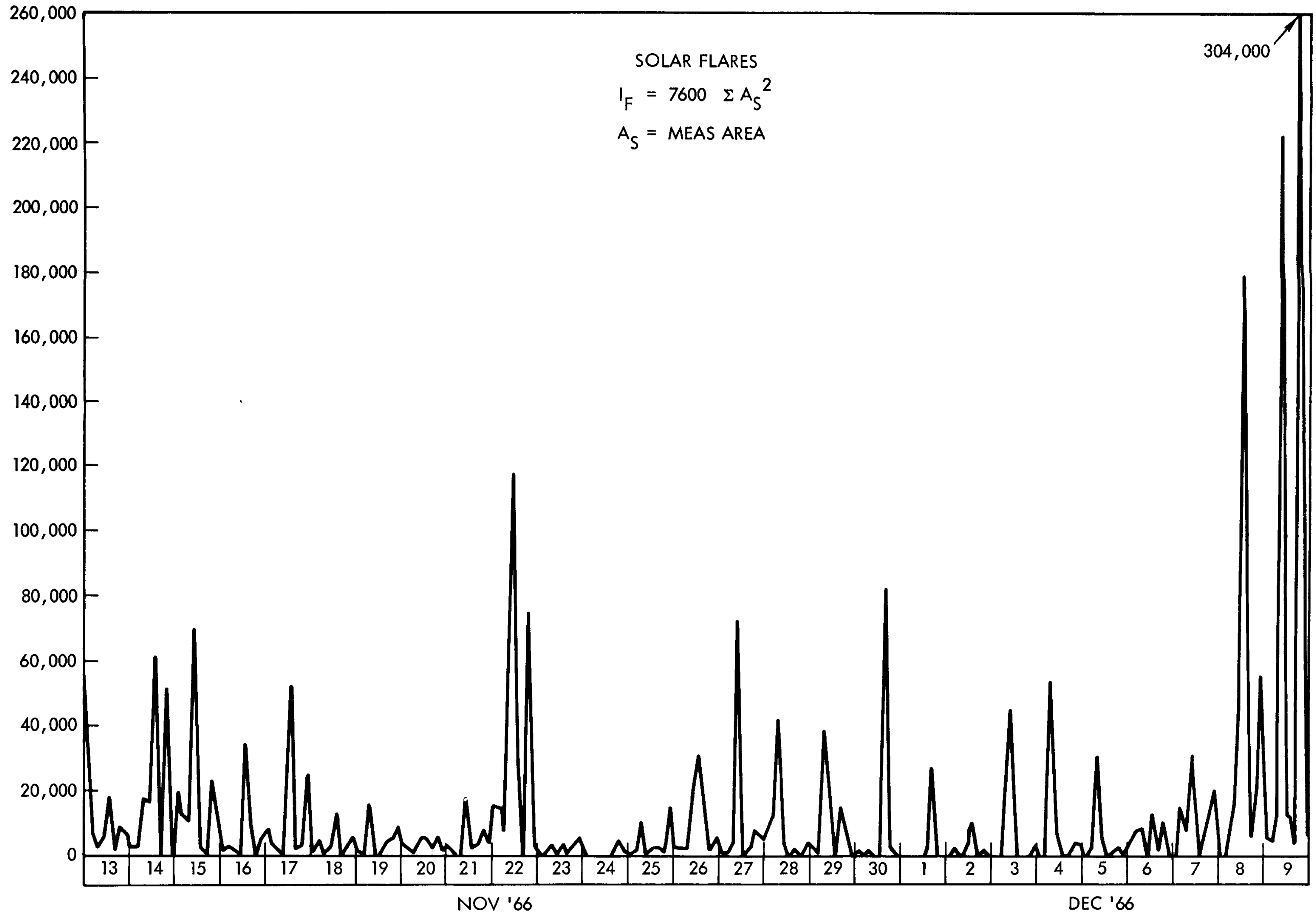


Figure 6. Solar flare index emphasizing large events.

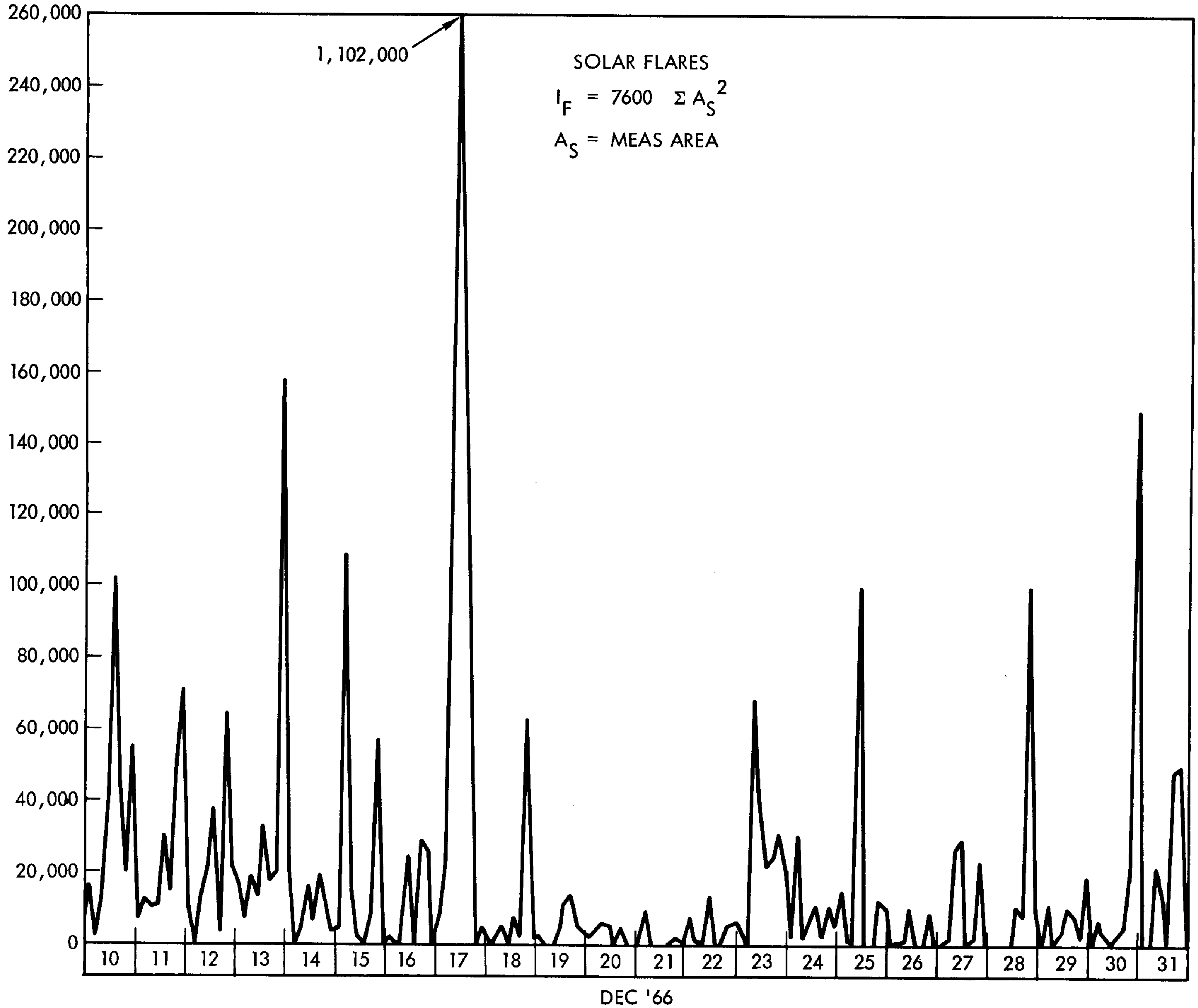


Figure 7. Solar flare index emphasizing large events.

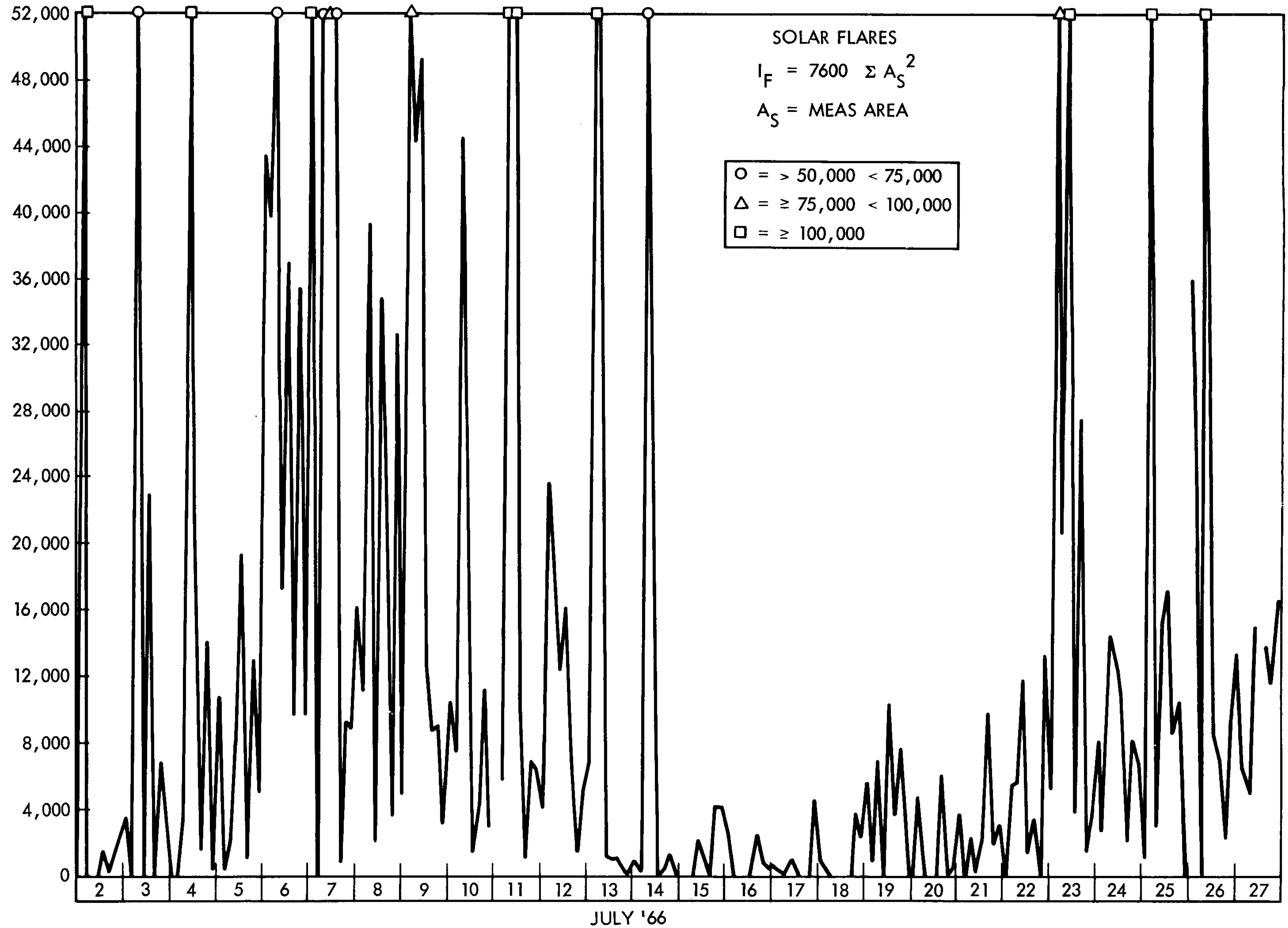


Figure 8. Solar flare index emphasizing background level.

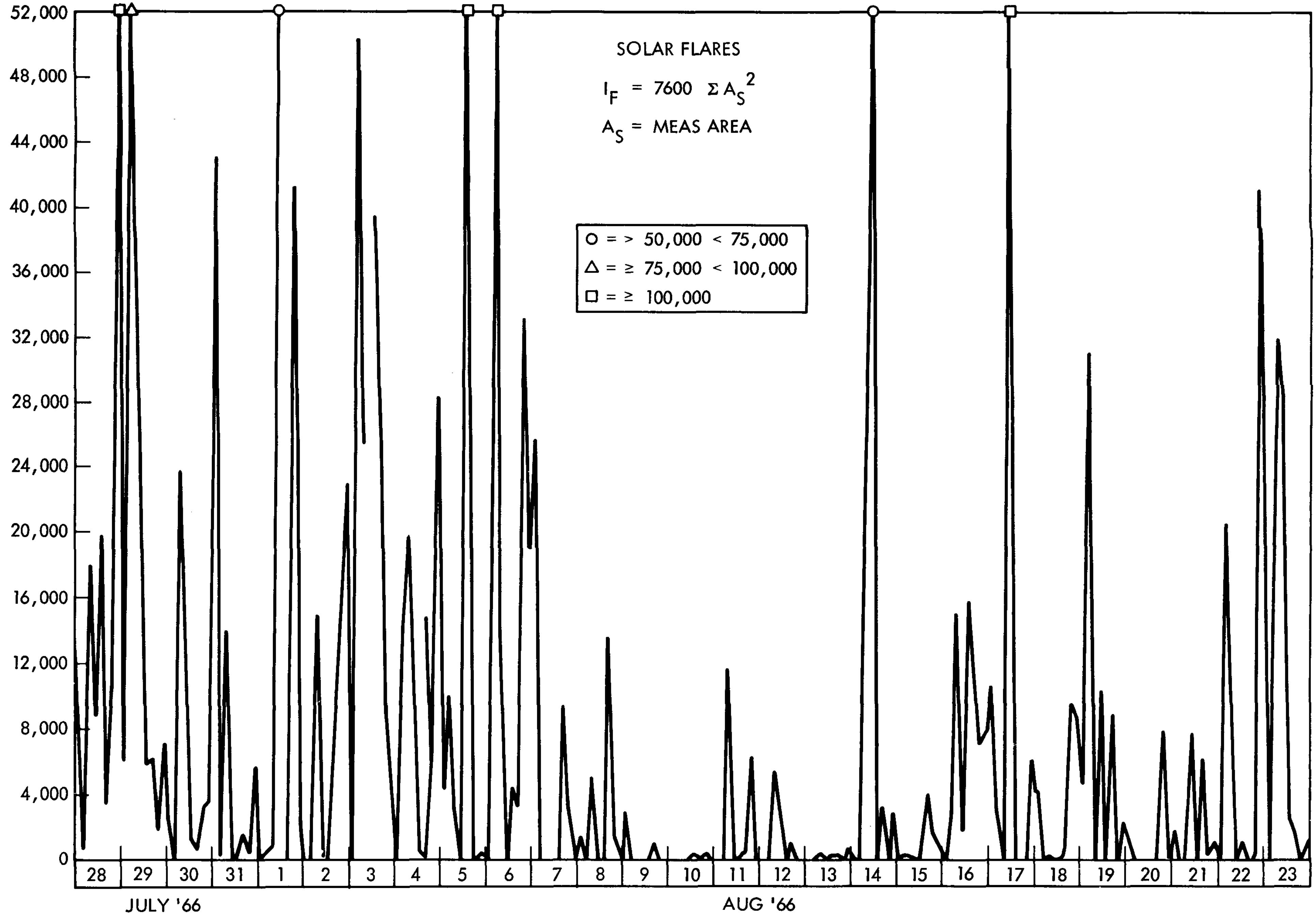


Figure 9. Solar flare index emphasizing background level.

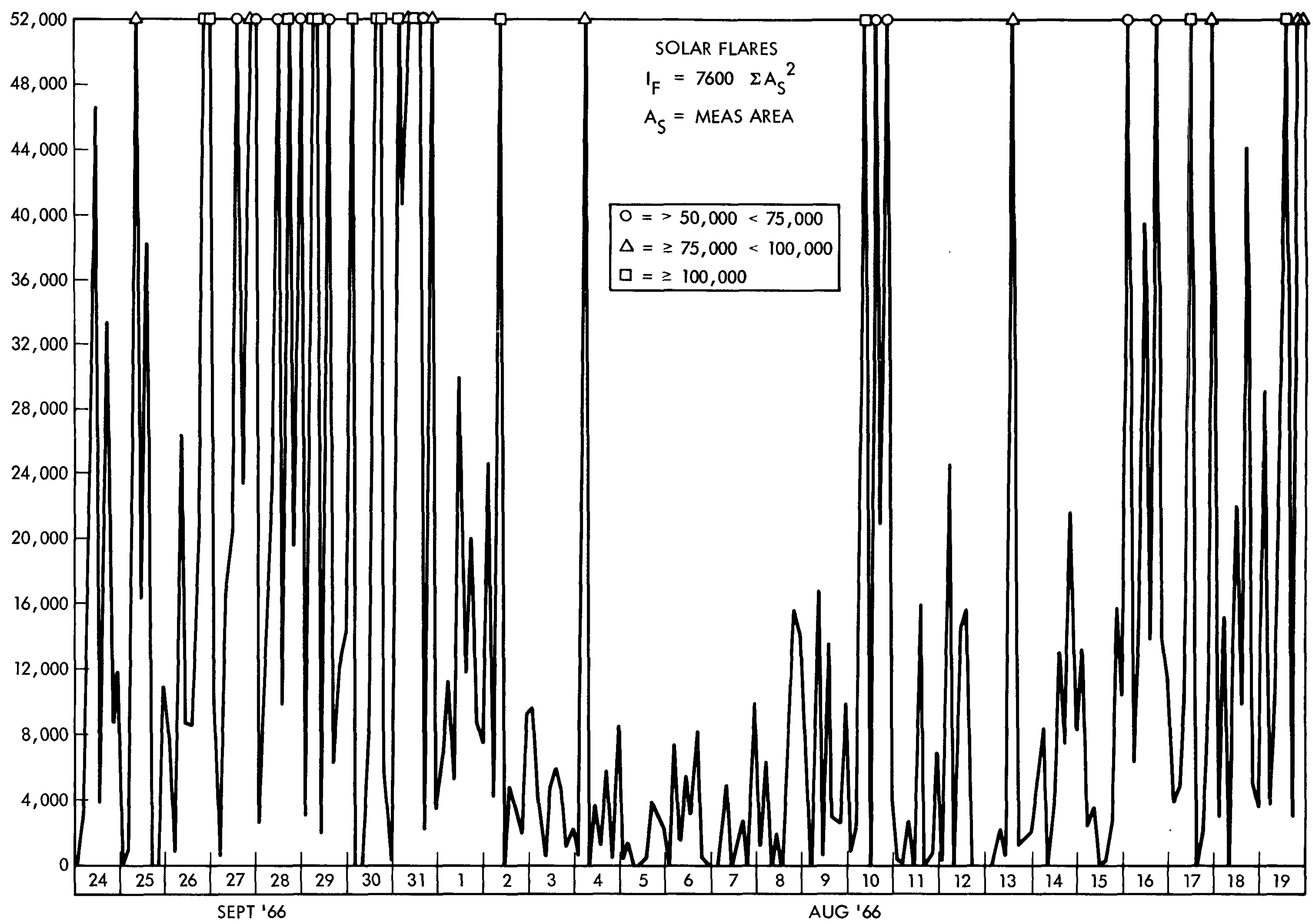


Figure 10. Solar flare index emphasizing background level.

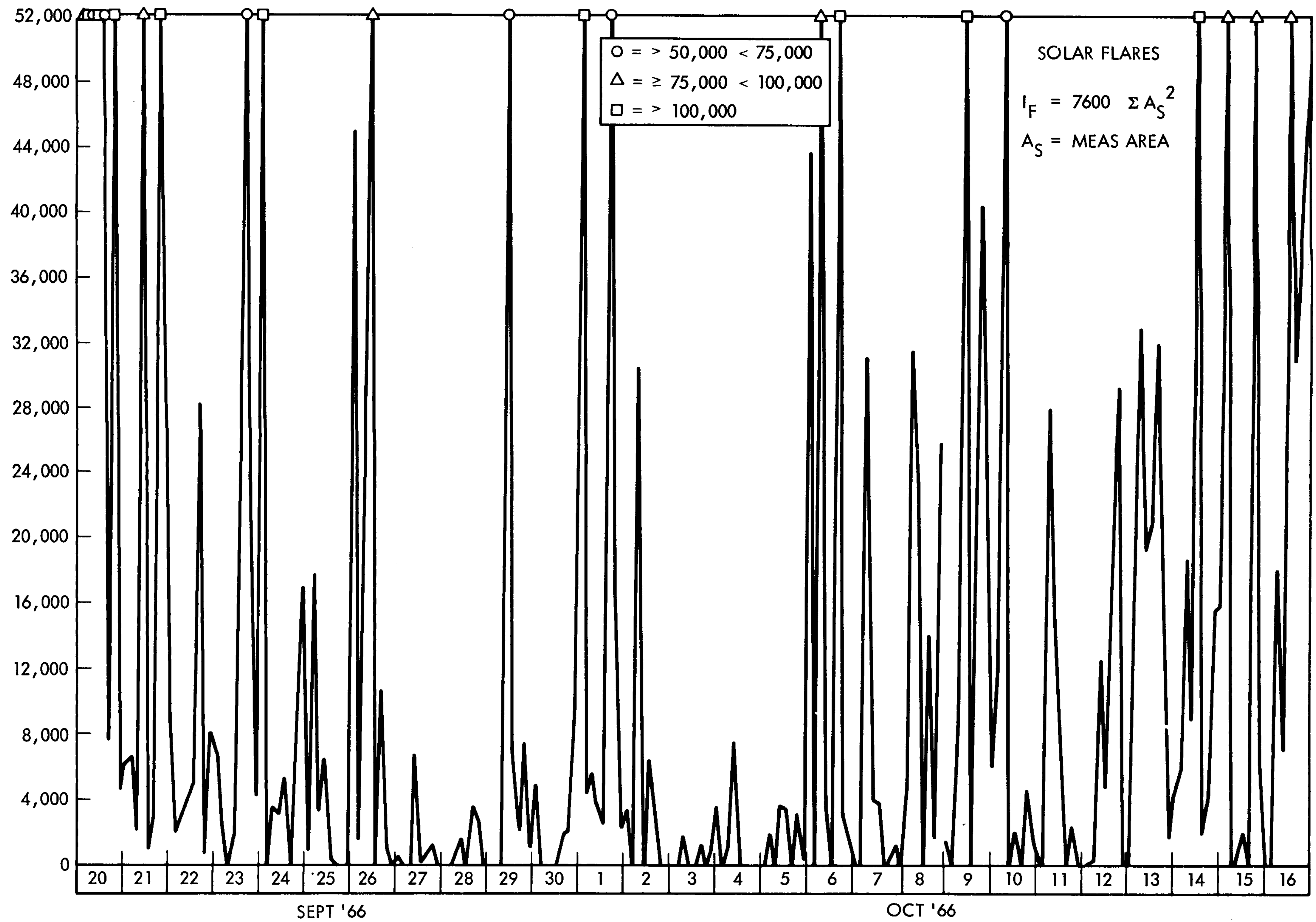


Figure 11. Solar flare index emphasizing background level.

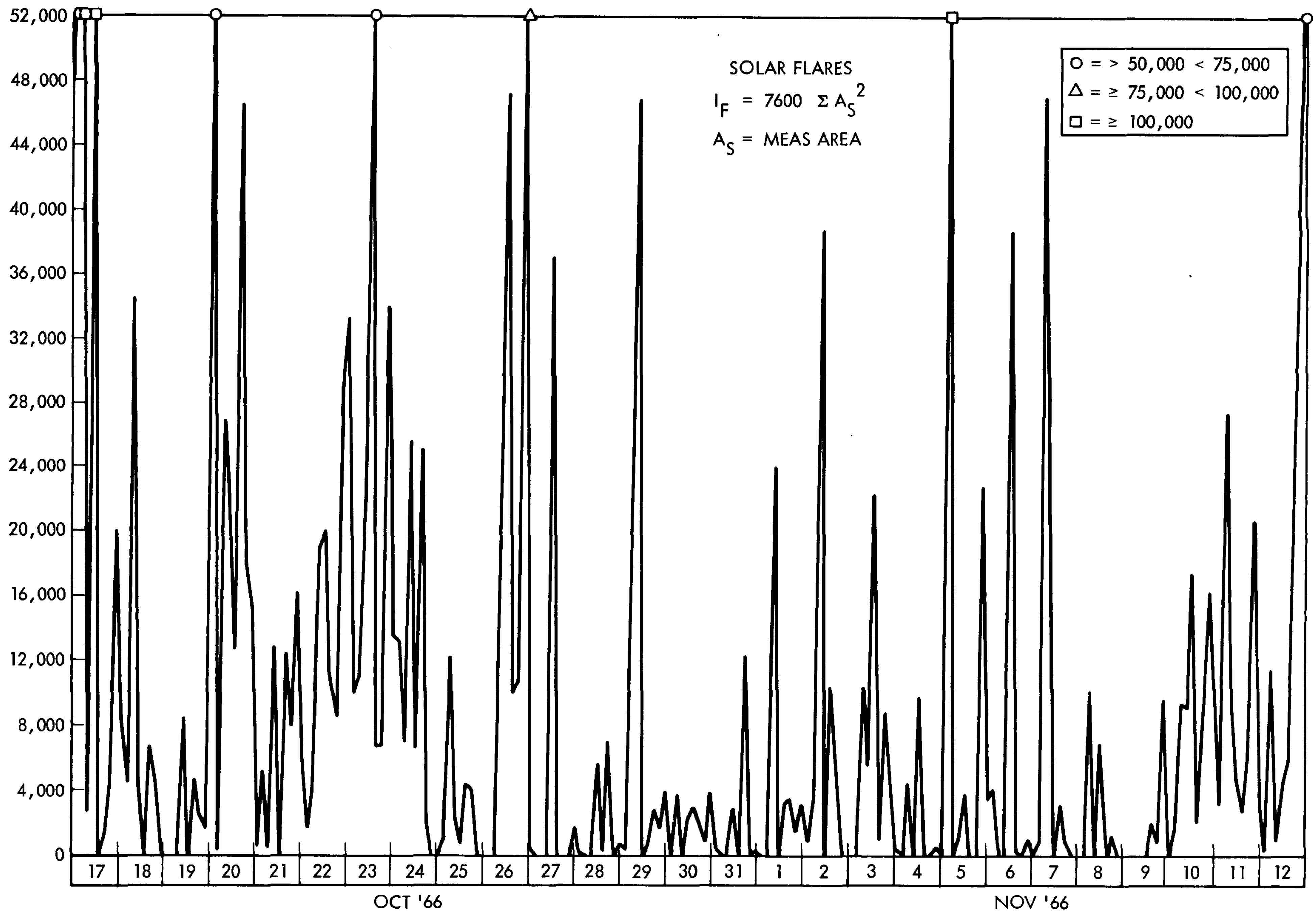


Figure 12. Solar flare index emphasizing background level.

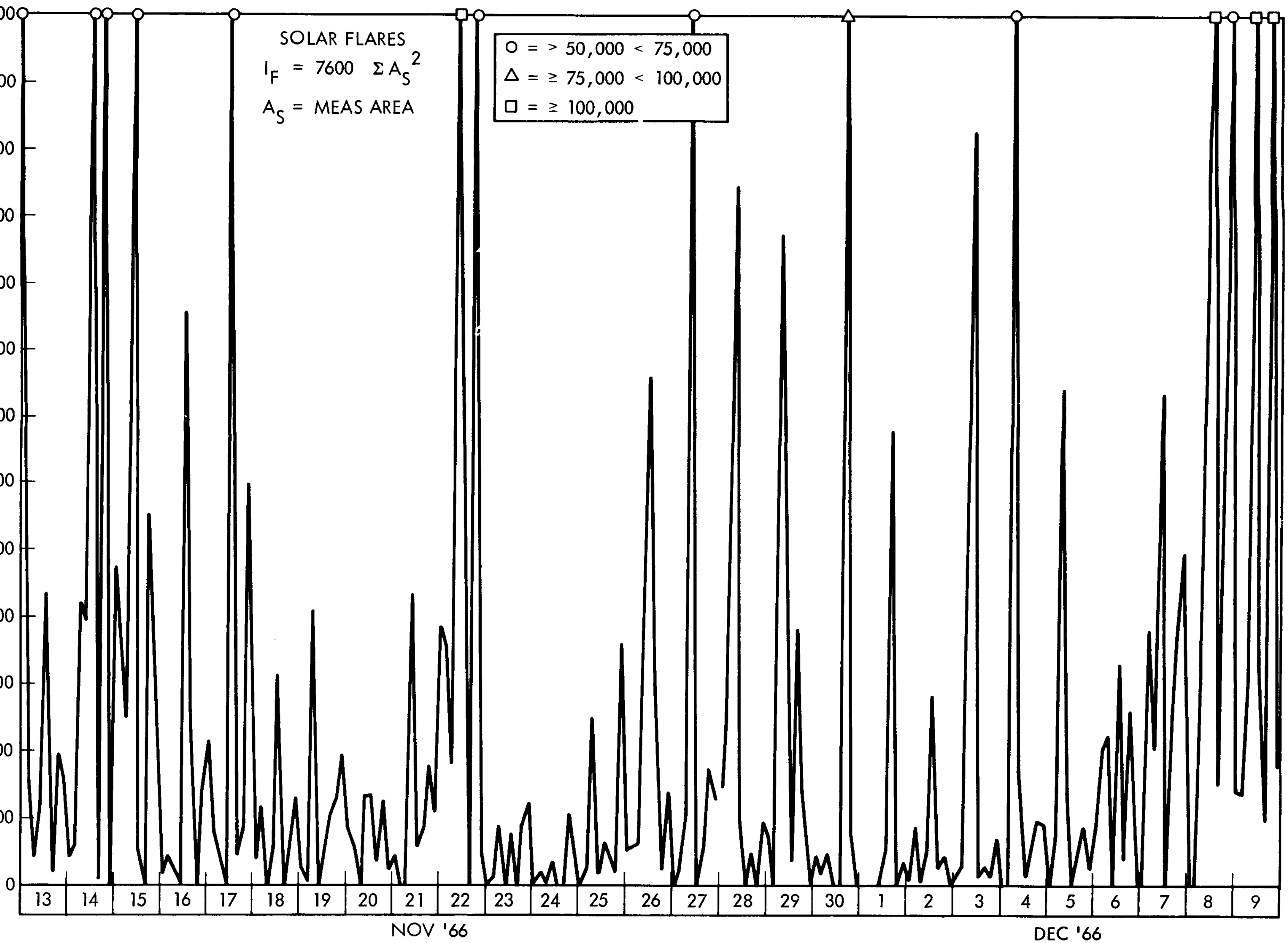


Figure 13. Solar flare index emphasizing background level.

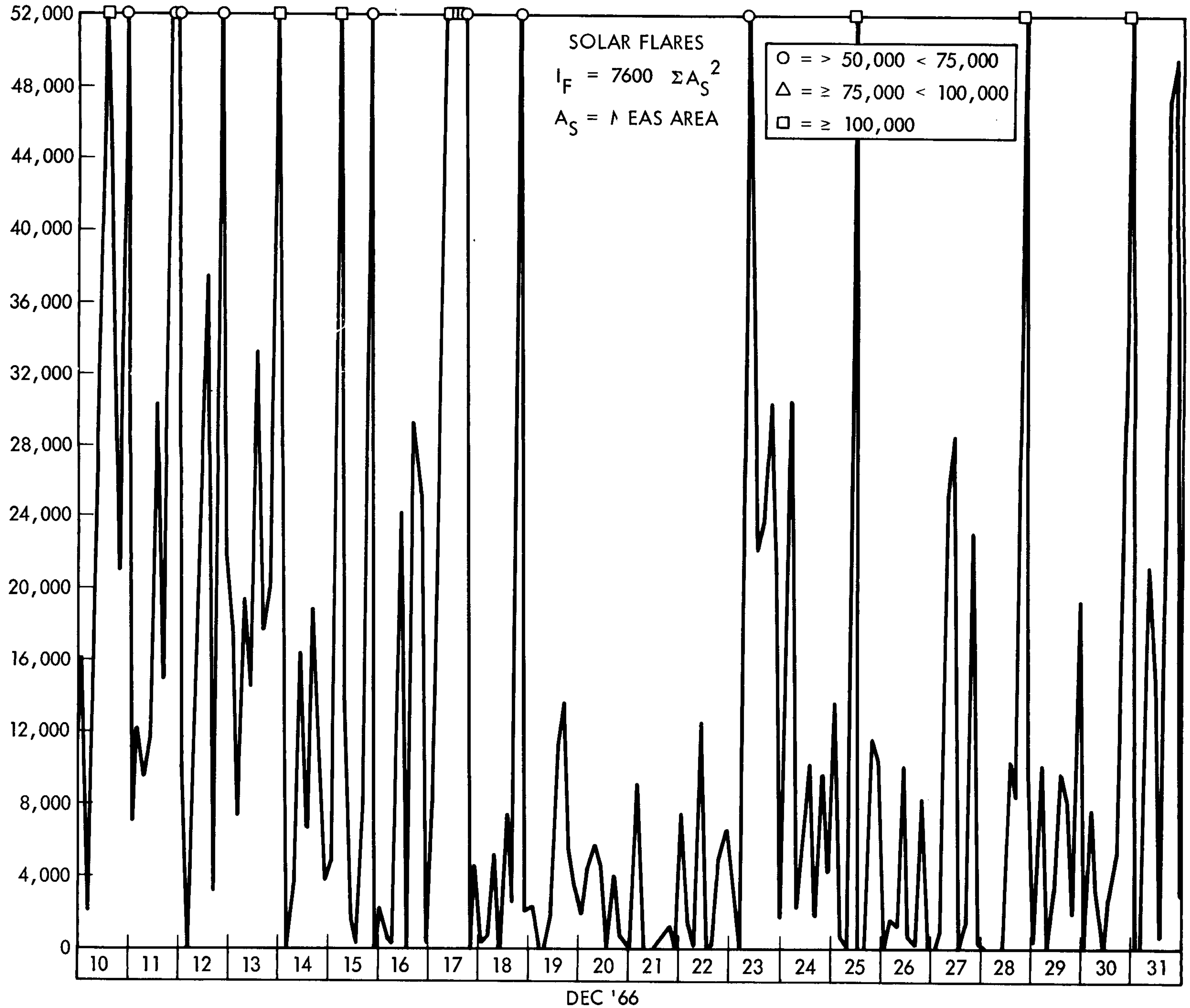


Figure 14. Solar flare index emphasizing background level.

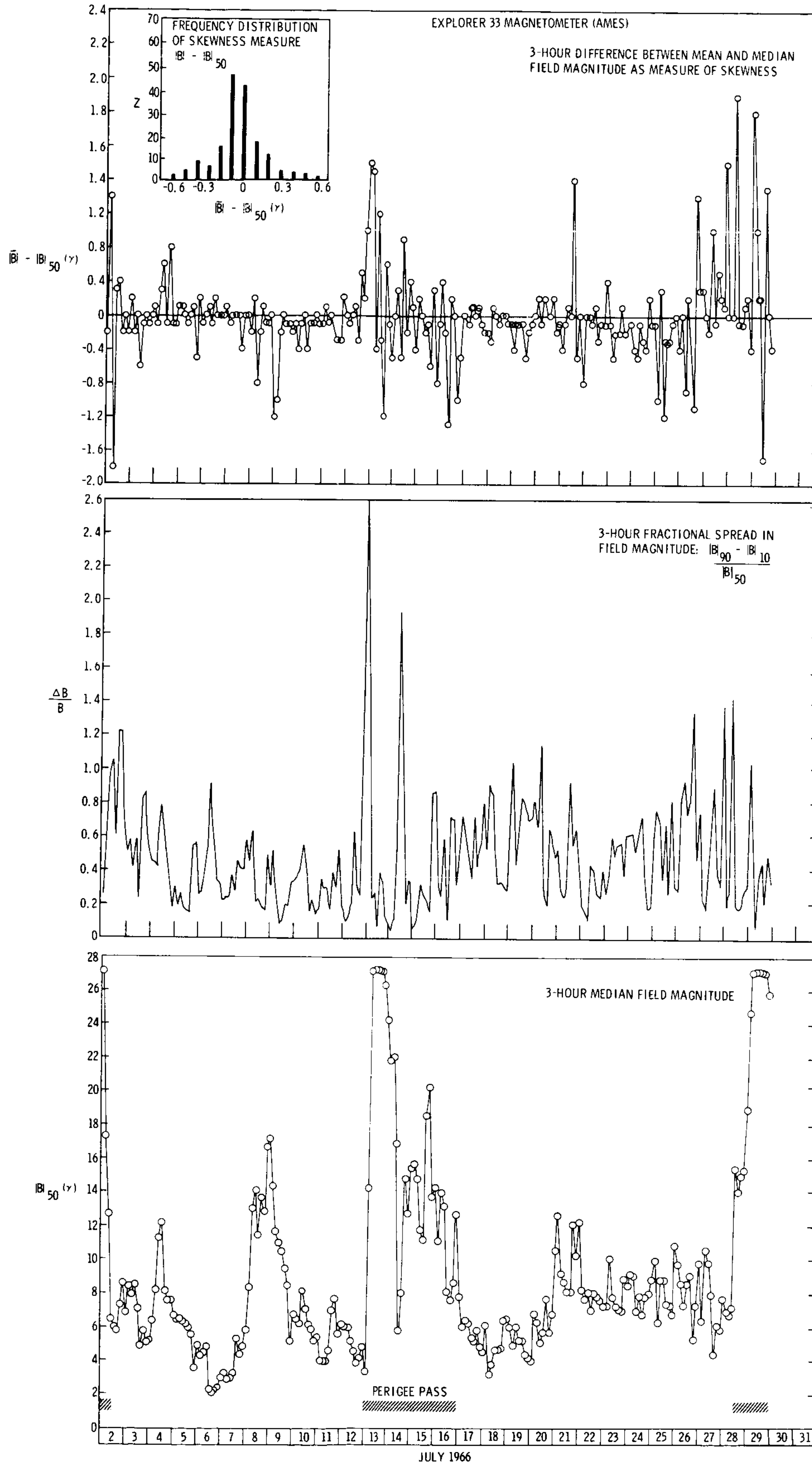


Figure 15. Some statistical characteristics of Explorer 33 three-hour interplanetary field distributions.

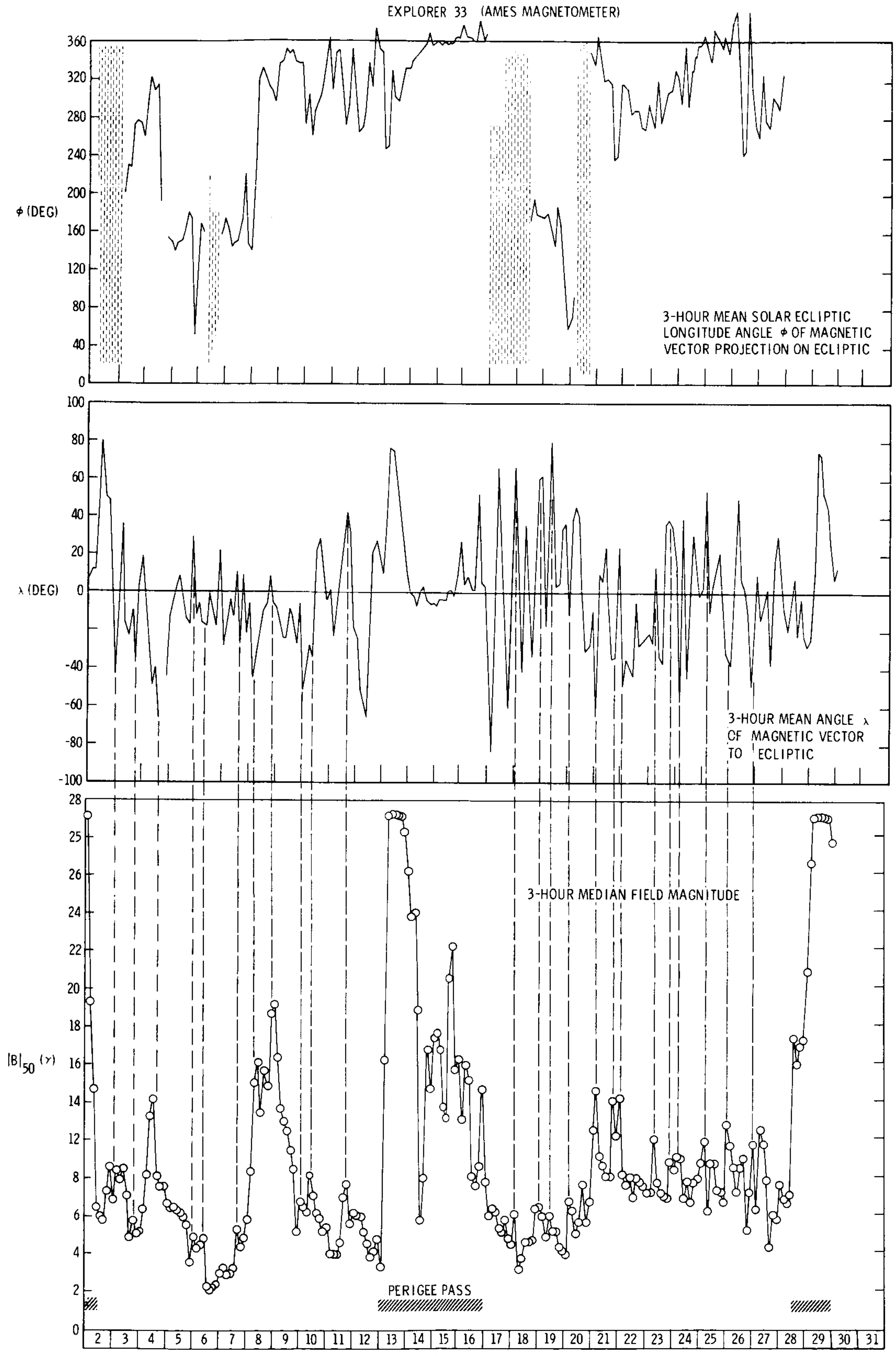


Figure 16. Time behavior of Explorer 33 three-hour mean field vectors.

PROTON FLARE OF JULY 7th 1966 AND THE ASSOCIATED ACTIVE REGION ON THE SUN

ON THE DEVELOPMENT OF THE ACTIVE REGION
SUMMARY BY M.J. MARTRES AND M. PICK (Meudon Observatory)

With the collaboration of C. POPOVICI and A. DIMITRIU, T. FORTINI and M. TORELLI, L. DEZSŐ and P.S. Mc INTOSH, M.N. GNEVISHEV and Mrs GNEVYSHEVA, J. L. LEROY and J. SYKORA, J. TANAKA, T. KAKINUMA and S. ENOME, H. FRIEDMAN and R.W. KREPLIN.

The solar region respectively named by Mount Wilson Observatory, Mc Math Observatory and Meudon Observatory as 21034, 8362 and 1505 15, is located at 21C 34 N and is recognized by all the observers as being constituted by many elements. These different elements appear successively in the interval of a few hours. They are shifted eastward by a few degrees in longitude from a large, faculae region which is de creasing in area and has no visible spots (T. Fortini - M. Torelli).

On June 28, the first bright grain arrived at the same time as the general enhancement of the preexisting calcium network in the region. A few hours before the appearance of the second bright facular grain (fig.1) several authors have distinguished a dark oval. This oval is interpreted as being a cell of supergranulation (Fortini - Torelli - Mc Intosh) (1). In agreement with the observations of Bumba and Howard (2), the new active region expands at the edge of three connected supergranules (Mc Intosh). The second bright facular grain is located at the place where the sunspots of June 30 will appear.

Mc Intosh notes that the development is marked by the successive appearance of three pairs of sunspots, respectively June 30.5, July 1.5 and July 3.1 . Each pair presents the normal polarity of a bipolar group but we can note that the inclination of each pair to the meridian is abnormal.

The respective positions of these three groups are quite remarkable. Since their appearance, the sunspots constitute two ranges of inverse polarity. The general inversion line is roughly parallel to the equator, and the western following spot is close to the eastern leading spot. It is exactly at this location that the classical δ configuration will build up between July 4 at 14^h04 and July 5 at 7^h55 (figure 2) ; this δ configuration is characterised by spots of inverse polarity in the same penumbra (3). The proton flare of July 7 will develop on this configuration.

In fact, if the δ configuration is already visible by July 5 we must note that the high resolution photograph from the Sacramento Peak Observatory shows at 15.30 a large compact umbra for the north spot. However, the south spot is formed by a large number of small umbrae (figure 3).

Between the two observations of July 5 at 15.30 UT and July 6 at 14.30 UT, the two predominent elements of the active region attained a state of equilibrium. This step in the development does not coïncide with the maximum of the area of the group, but rather with the maximum of the only spot area which constitutes the δ configuration. It is more precisly called an A configuration because equilibrium has been attained (4) (figure 4).

It is interesting to compare this result with the study of C. Popovici and A. Dimitriu. They indicate that on July 3, between 10 UT and 18 UT, the H_α bright plage takes a compact and elongated form. This aspect takes place just after the appearance of the third pair of spots and persists on the following days. They make a comparaison between the evolution of sunspot and area of the bright plages in H_α. Popovici and Dimitriu show that in time the developments are not comparable ; the maximum of the H_α bright plages is reached on the 6th of July and remains until the maximum of sunspot area (roughly July 9).

We can conclude that the formation of the appropriate configuration necessary to the production of a proton flare takes place from a favorable location among the spots. The A configuration was definitively built up sometime between July 5 and July 6 (14.32). It also appears that the shape, the disposition and also perhaps the variation of the brightness (H_α plage or sunspots) is revealing the first step of a proton flare. They complete the indication given by the optical morphology and the magnetic configuration.

The fine structure of the group in white light and more precisely of the central portion appears remarkable beginning on July 5. Mc Intosh notes that ten hours before the flare, the penumbra between the two spots becomes unusually dark.

Popovici and Dimitriu also point out that 12 hours before the proton flare the plage exhibits two bright filaments which have a symmetrical disposition with respect to the axe of the group and just cover the penumbra of the two ranges of spots (fig 5).

In addition, during the twelve hours preceeding the proton flare Mrs. Prince-Dodson reports a continuous production of small flares with increasing area from one subflare to the following one. She also reports motions of absorbing material closer and closer to the large spot of North polarity.

Each of these facts are indicators of a preparation of the active region which starts about from July 3, but is suddently accelarated twelve hours before the flare.

Very roughly , it seems that we can distinguish two phases in the development of the active region before the proton flare. The first phase leads to the formation of the appropriate structure, whereas the second phase, which begins somewhere between the 5th and 6th of July is the elaboration of the proton flare itself.

This conclusion is reinforced by the evolution of the optical and radio activity of the group. The number of bursts observed in the centimetric and decimetric domain is strongly increasing July 6 (figure 5).

Let us now look at the evolution of the active center at radio wavelengths. Figure 7 showsthe 9.1 cm spectriheliograms for July 3 and July 6 (Stanford).

According to different observatories, the radio emission responsible for the slowly varying component is observed at centimetric and decimetric wavelenghts beginning the 2nd or 3rd of July (Tanaka-Kakinuma and Enome). That day roughly corresponds to the first appearance of the sunspots. For each radiofrequency, we can note that the general evolution of the radioflux is the same as the evolution of the sunspot area.

The comparaison between figures (4) and figures (8) shows that the flux is increasing as the total spot-area up to the 8th of July and is rapidly decreasing on the following days.

Nevertheless the shape of the radio spectrum shifts to higher frequencies during the life of the active center. Figure (9) shows that until the 4.5th of July, we observe that the flux density decreases with increasing frequency between 4 GHz and 9.4 GHz. That corresponds to the spectral shape exhibed for the majority of the active centers (5). A sudden onset of the flux which is especially marked at about 9.4 GHz takes place between the 4.5th and 5.0th of July. So in the 4 GHz - 9.4GHz frequency interval, the spectrum becomes relatively flat (Tanaka - Kakinuma and Enome). This feature is this reported by Tanaka and Kakinuma (7) for the active centers producing proton emissions or type IV bursts.

More precisely, this feature of the high frequency radiation is very likely associated with a change of the magnetic structure rather than an enhancement of the sunspot area (8).

Indeed, we formerly reported that important changes in optical aspect take place between the 4th and 5th of July, which lead to the classical configuration of the proton centers.

This fact is clearly seen on figure (1) where we have gathered together the data concerning the evolution of the flux at different frequencies and the evolution of the sunspot area. For the frequencies equal or shorter than 4 GHz the radio development is similar to the optical. On the other hand at 9.4 GHz we observe a discontinuity on July 5. The theory of the slowly varying component should take this peculiarity of the high frequency radiation into consideration.

Let us now consider the resluts of the X ray data. It is interesting to note that, on July 4, H. Friedman and R. W. Kreplin observe the first indications of increasing X.R. emission. Despite the considerable variability, the flux strongly increases after July 5.5 . This fact is easily seen on the curves corresponding to the 0-8Å and 8 Å - 20Å flux (fig 1b).

We now try to draw some conclusions on the general evolution of the active center. We formerly noted that the center reaches an appropriate structure at about July 5. At radio wavelengths, this structure corresponds to the formation of a specific spectral shape.

Beyond July 5, during the elaboration of the proton flare, we observe a strong increase of the radio and optical activity, and also a strong enhancement of the X.R. flux.

Table I summaries the chief properties of the evolution of this center.

To improve our understanding of the development preceding a proton flare, it would be desirable in the future to follow continuously the magnetic structure and the evolution of a group just after the constitution of the A or δ configuration.

Development of the region after July 7 :

After cosmic ray flare, different authors find a decrease of sunspot area (8)(9). In this case in the few hours which follow the flare Mc Intosh and E. Sawyer observe that the northern member of the A configuration becomes clearer and the edges of the umbrae become more separated. This evolution proceeds at the same speed during the first day and at a slower speed there after. The part where the proton flare occurred decreases and becomes fragmented. But the data show that the total sunspot area still increases during the two days following the proton flare. This is caused by the development of the East and West parts of the group.

The radio evolution is not easy to study because the correction of the flux owing to the heliographic position of the active center is not well known and may be a function of frequency. It appears that on July 8 the radio spectrum still presents the same shape (figure 9).

The coronal data are difficult to interpret because the active center is born on the solar disk and we have no information on the evolution of the center while it passes from the East limb to the West limb. One interesting feature is that the maxima of the isophotes of coronal lines 6347 and 5303 are shifted toward the North pole (J.L. Leroy - M.N. Gnevyshev - Mrs Gnevysheva).

We are indebted to the optical and radio observatories fo Athènes Arcetri, Algonquin, Bucarest, Debrecen, Fleurs(Sydney), High Altitude Observatory, Honolulu, Kislovodsk, Kodaikanal, Lomnitskyshift, Mc Math, Manila, Meudon, Mount Wilson, Nançay, Pic du Midi, Sacramento Peak, Stanford, Tokyo and Toyokawa who have furnished many original records and have participated at this study. This list is certainly incomplete and we apologize for any omissions. We are also indebted to the National Research Laboratory.

Through the chief coordinator, we have received the interesting papers of Mrs Dodson and R. Hedeman, and of Mc Intosh and Mrs Sawyer which have been useful in the preparation of our summary.

We are grateful to Dr Svestka and Dr Simon for organizing the Proton Flare Project.

Table I

Date 1966	Optical features: White-light	Optical features: K_3	Optical features: Hα	Magnetic configuration	Radio	X-rays	Radio-bursts
June, 28 th		decreasing faculae					
29		bright grains "					
30	1st pair of spots	" development of the bright faculae		bp.			
July, 1st	2nd pair of spots	"					
2nd		" "			S component appears		
2,5		"					
3rd	3rd pair of spots	" " "	transformation of the bright plage		" " " "		
4th	increasing " "	" "	" "	complex " "	" Flat spectrum	indication of increasing	beginning of flare activity
4,5	"	"	"		4 GHz and 9.4 GHz	"	"
5	" "	" "	" "	δ configuration	"	"	"
5,5	"	"	" "	"	" "	" "	" "
6	" " " "	" " " "	" " maximum of area	A configuration (state of equilibrium) "	" " " "	strong increasing " "	strong increasing of number radio bursts
6,5	darkening of penumbra	" "	two bright filaments very near along the inversion line	" " "	" " "	" " "	" " "
7	"	" "		" "	" "	" "	" P.F.P.
7,5	fragmentation of umbrae and penumbra			decrease of the configuration			
8							

LEGENDS OF FIGURES

Fig. 1 : Active Regions in K_2 and K_3

A : Arcetri Observatory
K : Kodaikanal Observatory
M : Manila Observatory
M W : Mt Wilson Observatory
P : Paris-Meudon Observatory

from T. Fortini and M. Torelli,

Fig 2 : Drawings of spots - Approximate position in longitude and magnetic polarities.
Spectroheliograms K1V Meudon - Magnetic maps Crimea and Meudon.

Fig 3 : Photographs of Sacremento Peak in white light from . . P. S. Mc Intosh

Fig 4 : Daily variation of areas = White light from Mc Intosh - K1V Polarities North and South from Meudon Observatory.

Fig 5 : Photograph of H_α from C. Popovici, A. Dimitriu,

Fig 6 : Daily variations of number of flares and bursts from Kai with data of many observatories.

Fig 7 : 9.1 cm spectro heliograms for July 3 and July 6 from . . R.N. Bracewell (Stanford Observatory).

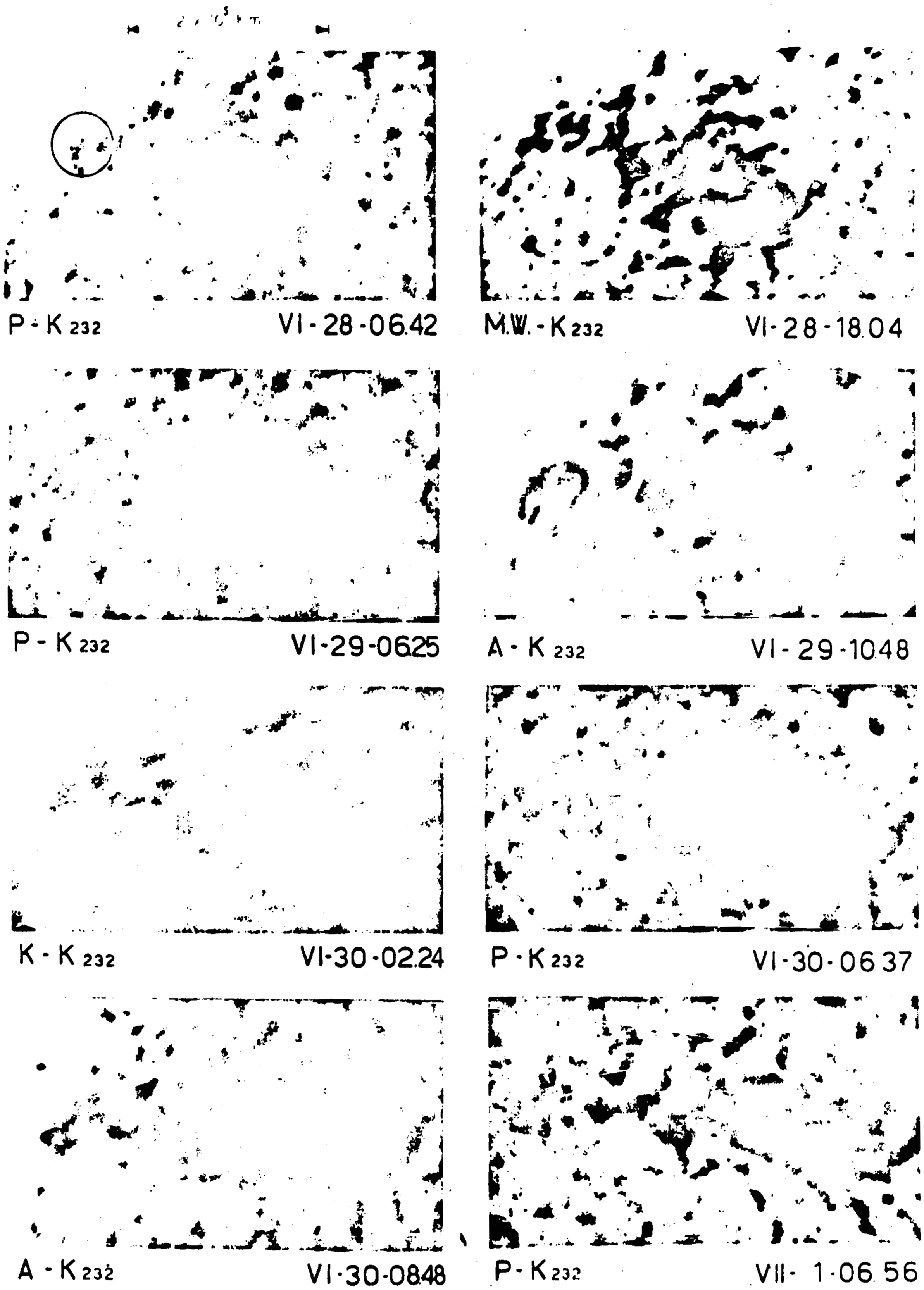
Fig 8 : Variations of flux density of the S. Component from J. Tanaka T. Kakinuma and S. Enome with the collaboration of many observatories.

Fig 9 : Variation of Spectrum of the S. Component from J. Tanaka, T. Kakinuma and S. Enome with the collaboration of many observatories.

Legends of figures

Fig 10 : Comparaison between the daily variation of total sunspot area and flux density at centimetric wavelengths.

Fig 11 : Variation of the X rays emission level from H. Friedmann and R.N. Kreplin (N. R. L. Sol rad 8 satellite).

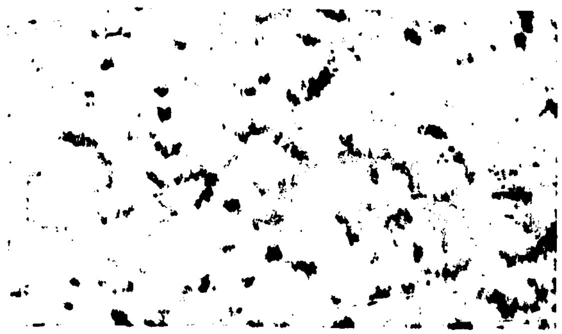


P - K 232
VI - 28 - 06.42
M.W. - K 232
VI - 28 - 18.04
P - K 232
VI - 29 - 06.25
A - K 232
VI - 29 - 10.48
K - K 232
VI - 30 - 02.24
P - K 232
VI - 30 - 06.37
A - K 232
VI - 30 - 08.48
P - K 232
VII - 1 - 06.56

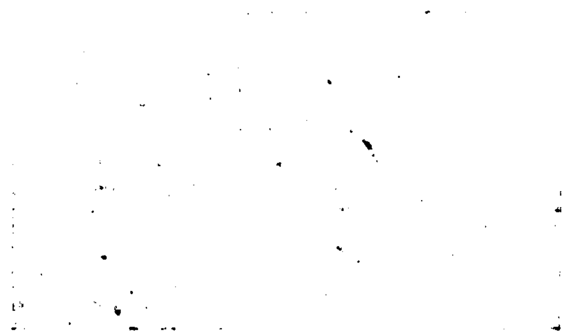
Fig 1a

A · K_{232} VII·1·08.56

M.W. · K_{232} VII·1·22.42



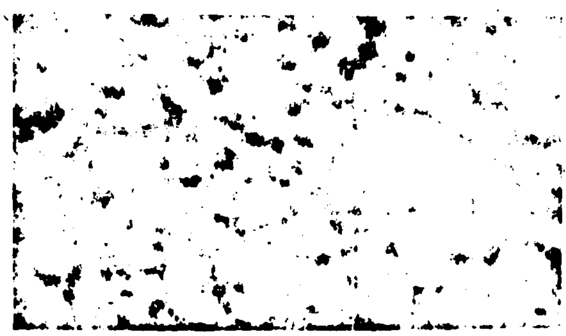
P · K_{232} VII·2·07.10



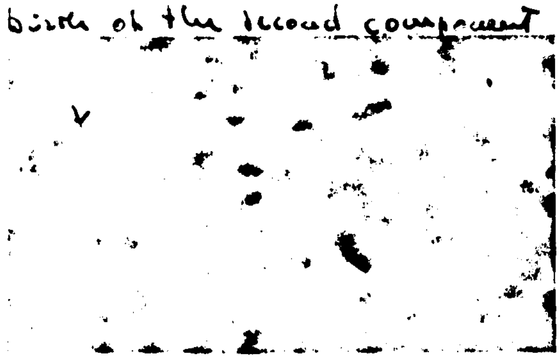
P · K_1 VII·2·06.50

M · K_{232} VII·2·23.25

birth of the second component

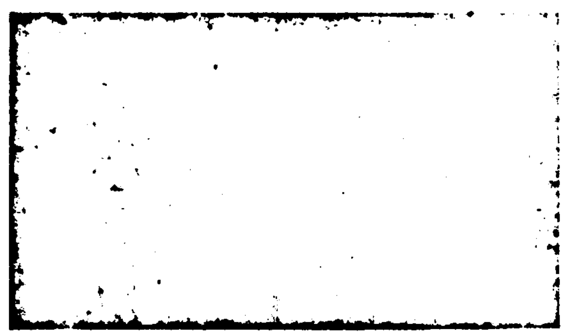


P · K_{232} VII·3·07.20



K · K_{232} VII·4·02.50

the two components have merged

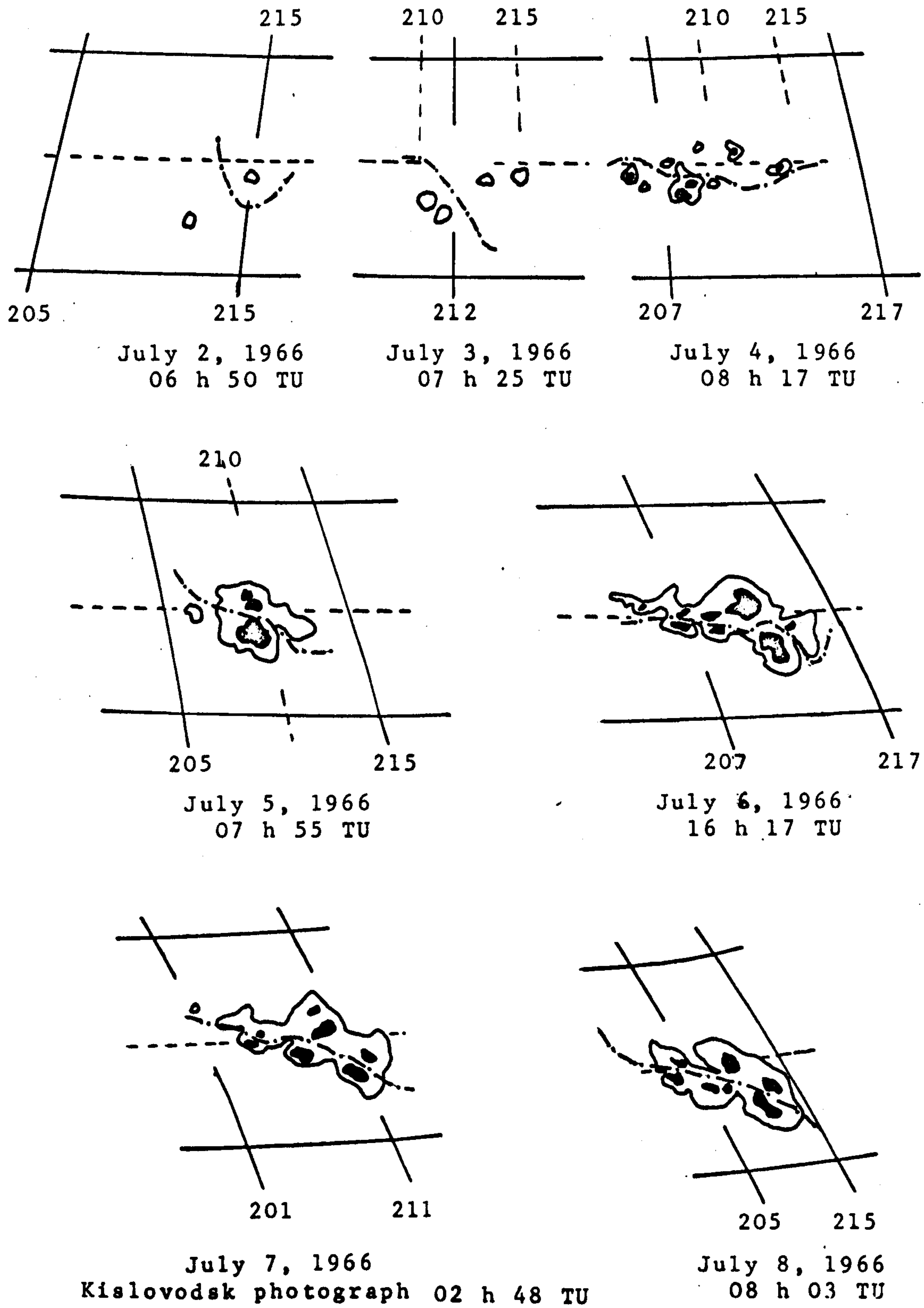


P · K_1 VII·4·08.27

Fig. 2b

P F P 1

Drawings of spots (1) Approximate positions in longitude and magnetic polarities (2).



(1) from spectroheliograms K_{1_v} (Meudon)

(2) from magnetic maps (Crimea and Meudon)

fig 2

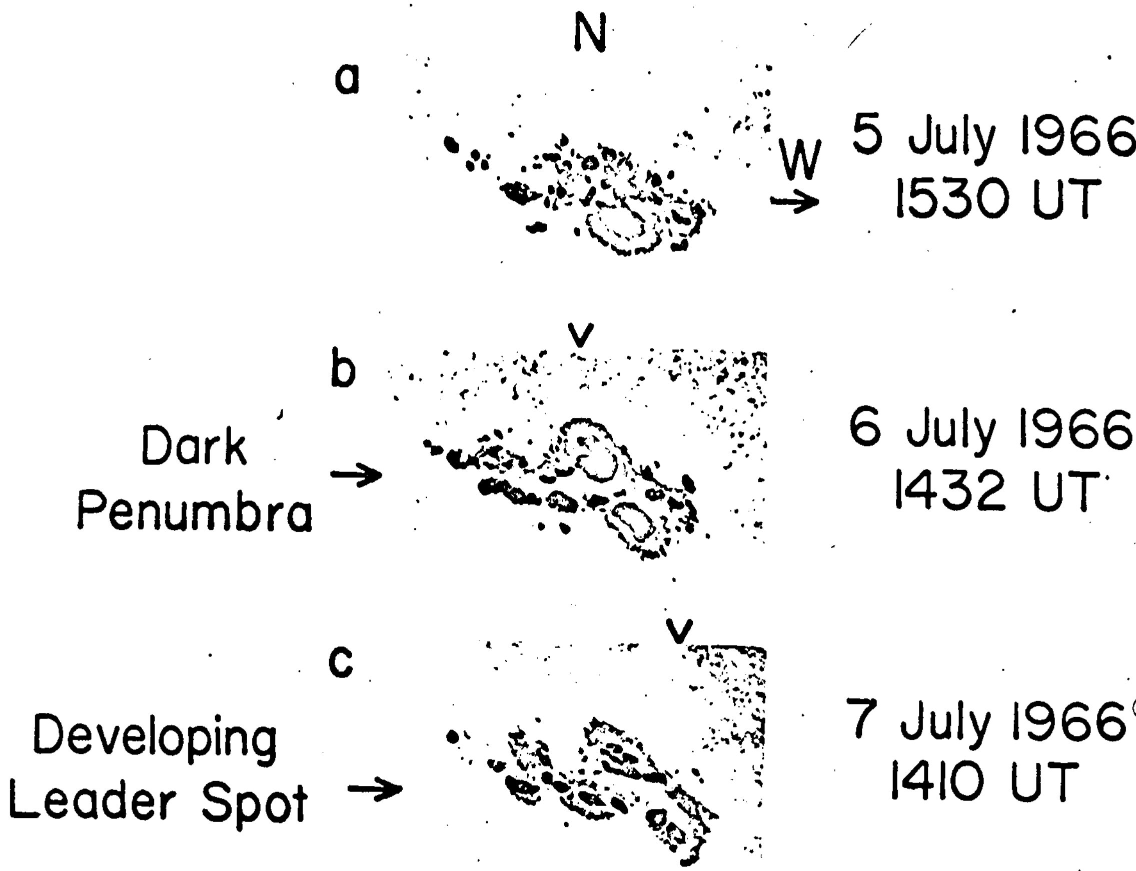

N
a
W
5 July 1966
1530 UT
b
Dark
Penumbra
6 July 1966
1432 UT
c
Developing
Leader Spot
7 July 1966
1410 UT

Fig. 3.

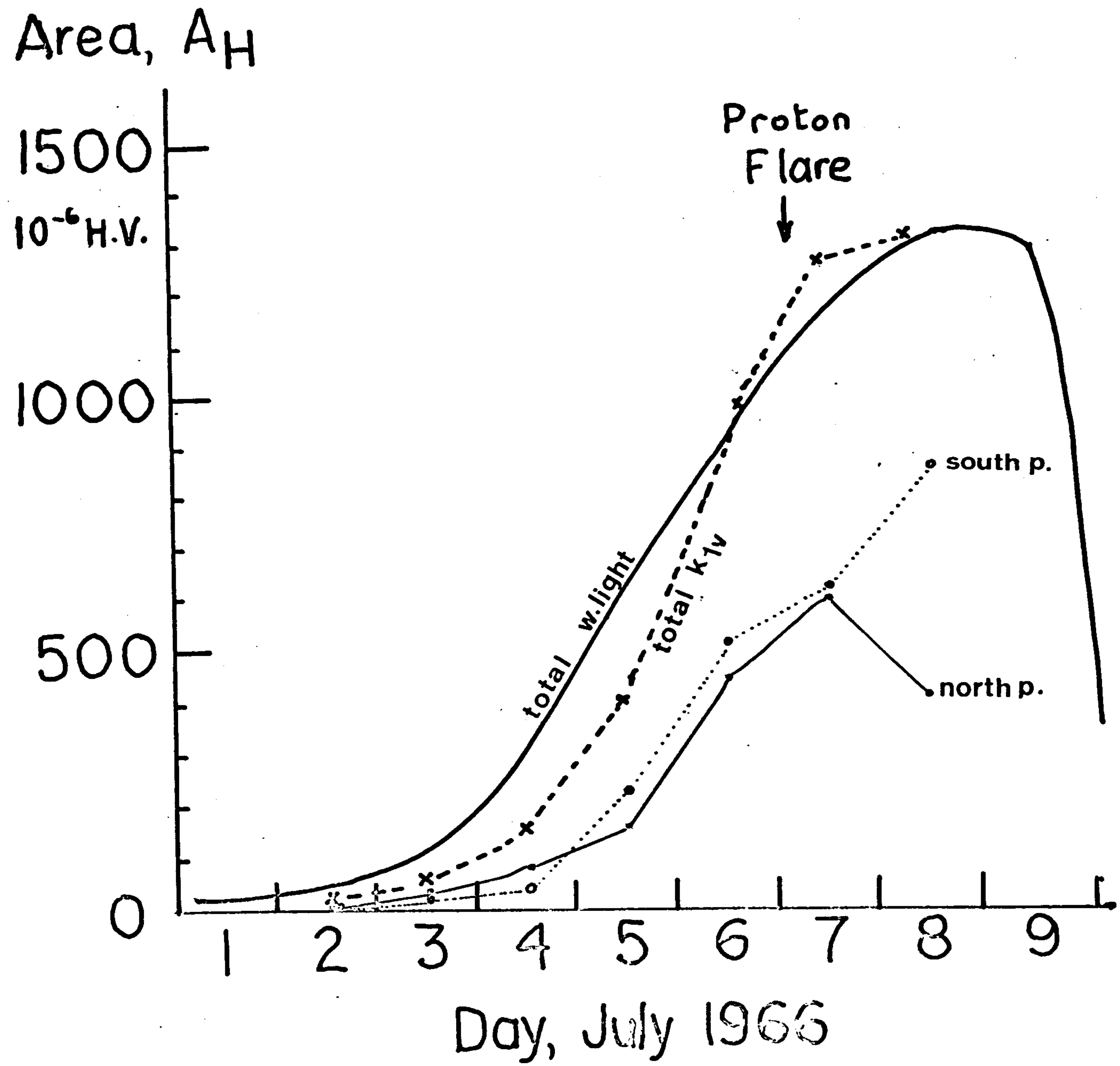

Area, A_H
1500
10^{-6} H.V.
1000
500
0
Proton Flare
total w.light
total K1v
south p.
north p.
1
2
3
4
5
6
7
8
9
Day, July 1966

fig 4

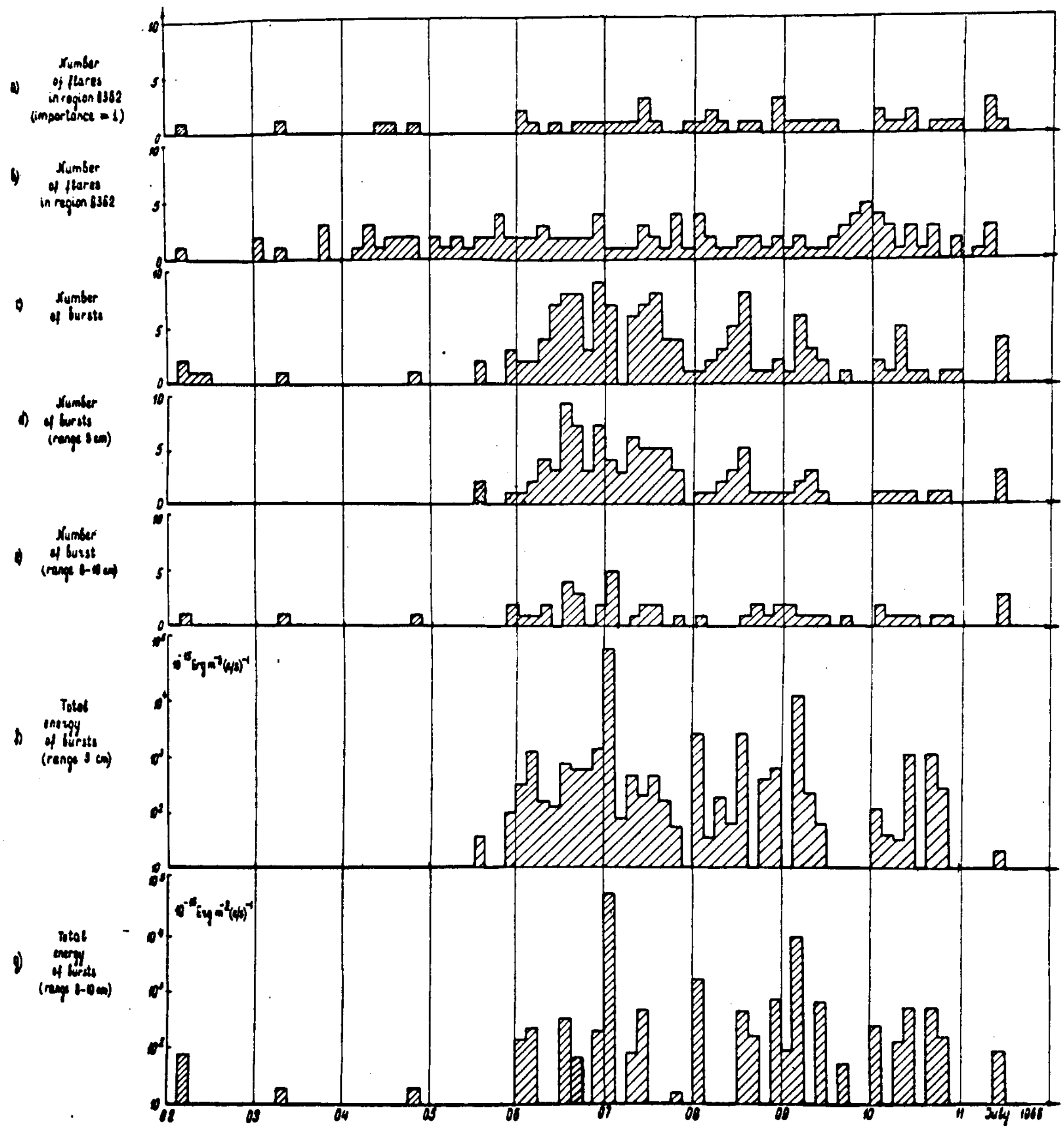

a) Number of flares in region 8362 (importance ≥ 1)
b) Number of flares in region 8362
c) Number of bursts
d) Number of bursts (range 3 cm)
e) Number of burst (range 8-10 cm)
f) Total energy of bursts (range 3 cm)
g) Total energy of bursts (range 8-10 cm)
02
03
04
05
06
07
08
09
10
11
July 1968

fig. 6

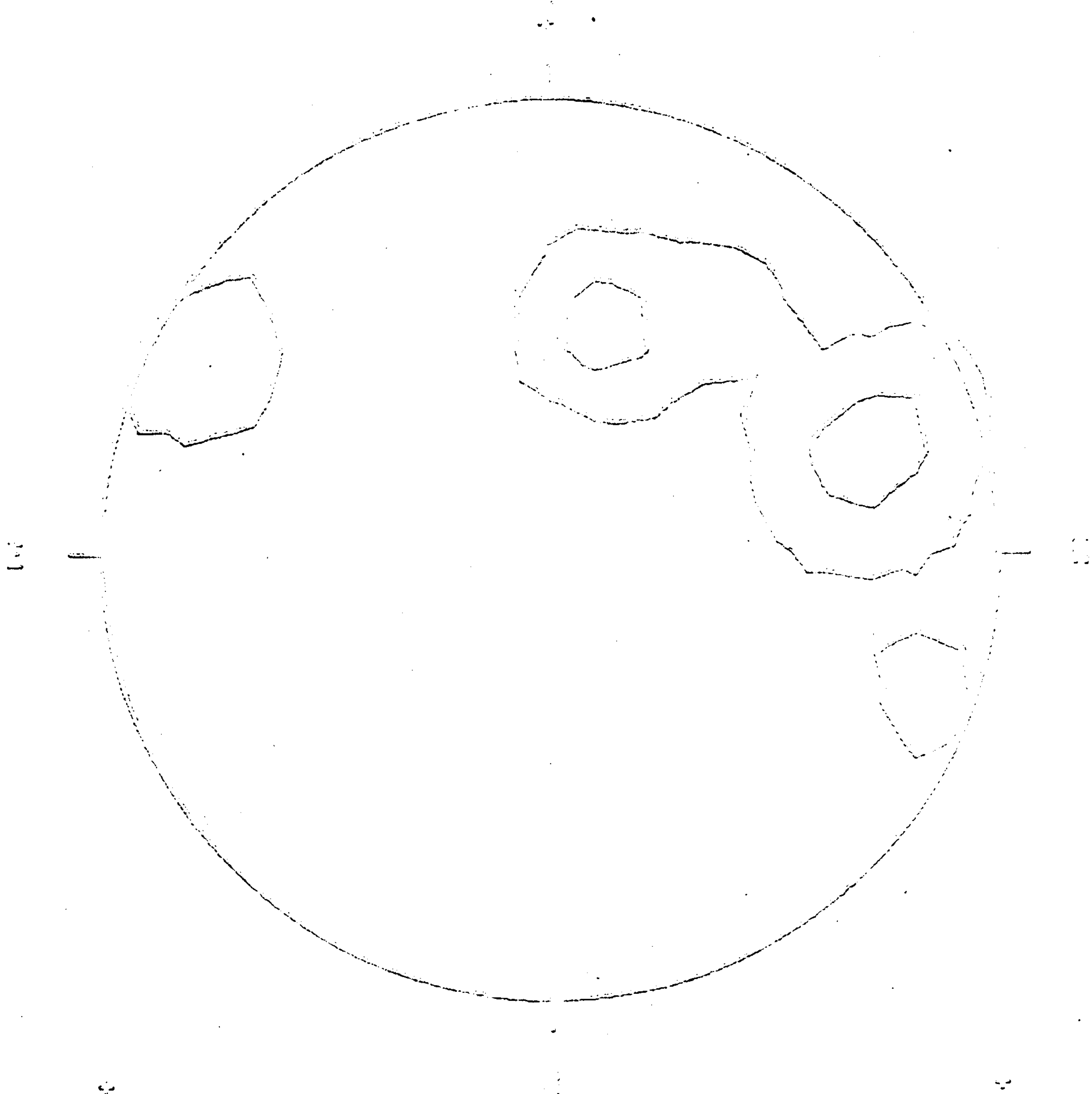
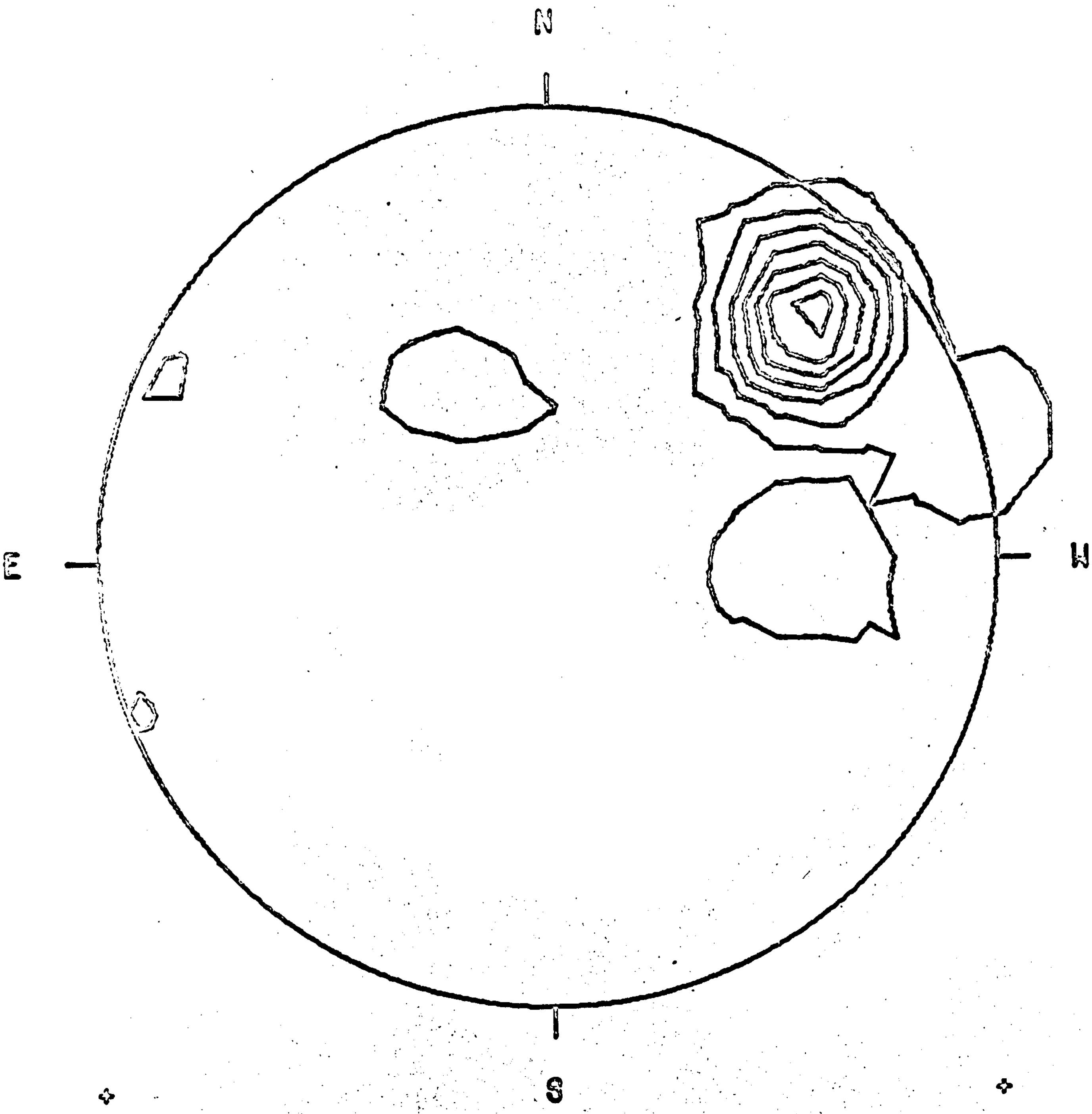


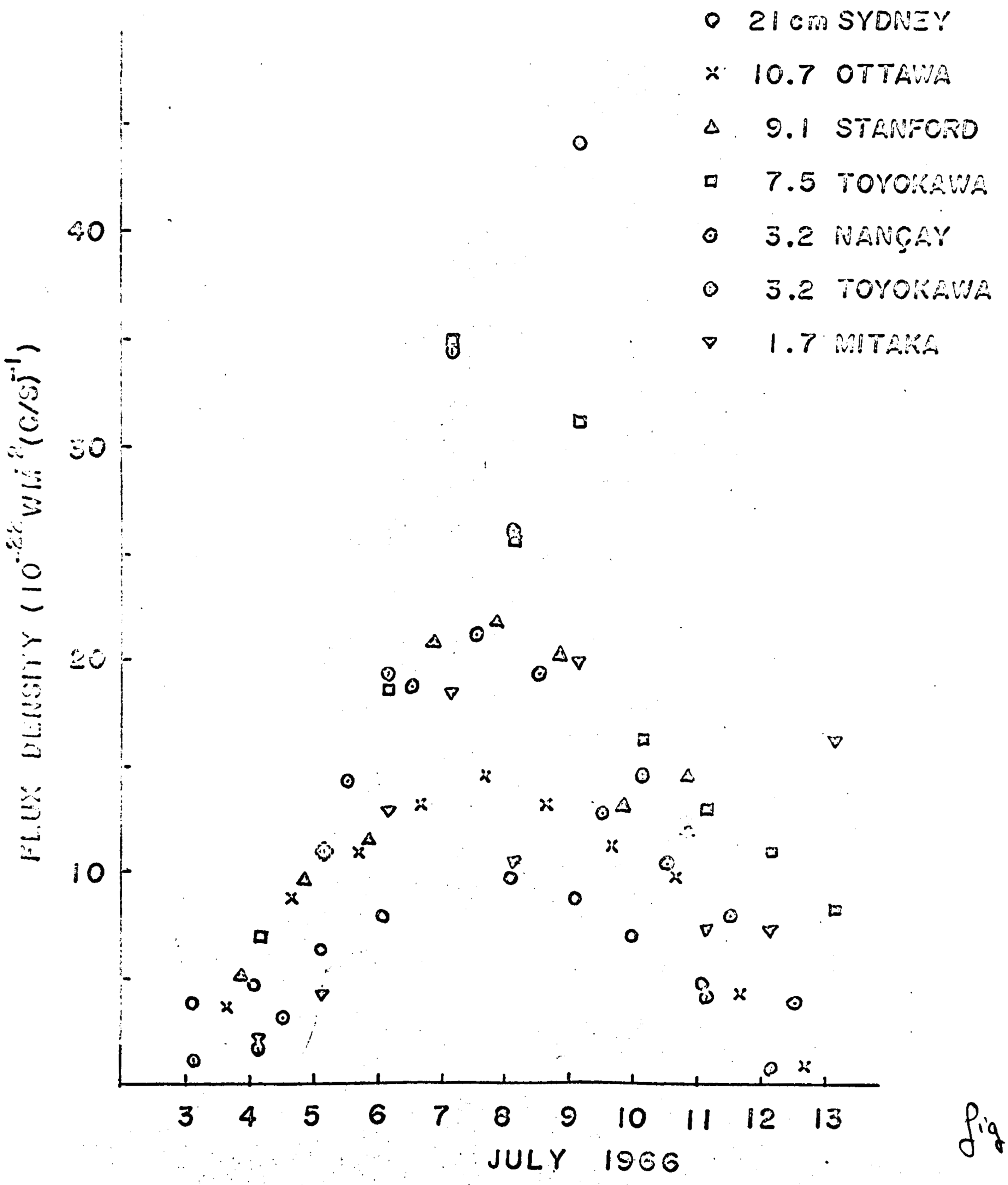
fig 7(1)



STANFORD 9.1 CM SPECTROHELIOGRAM

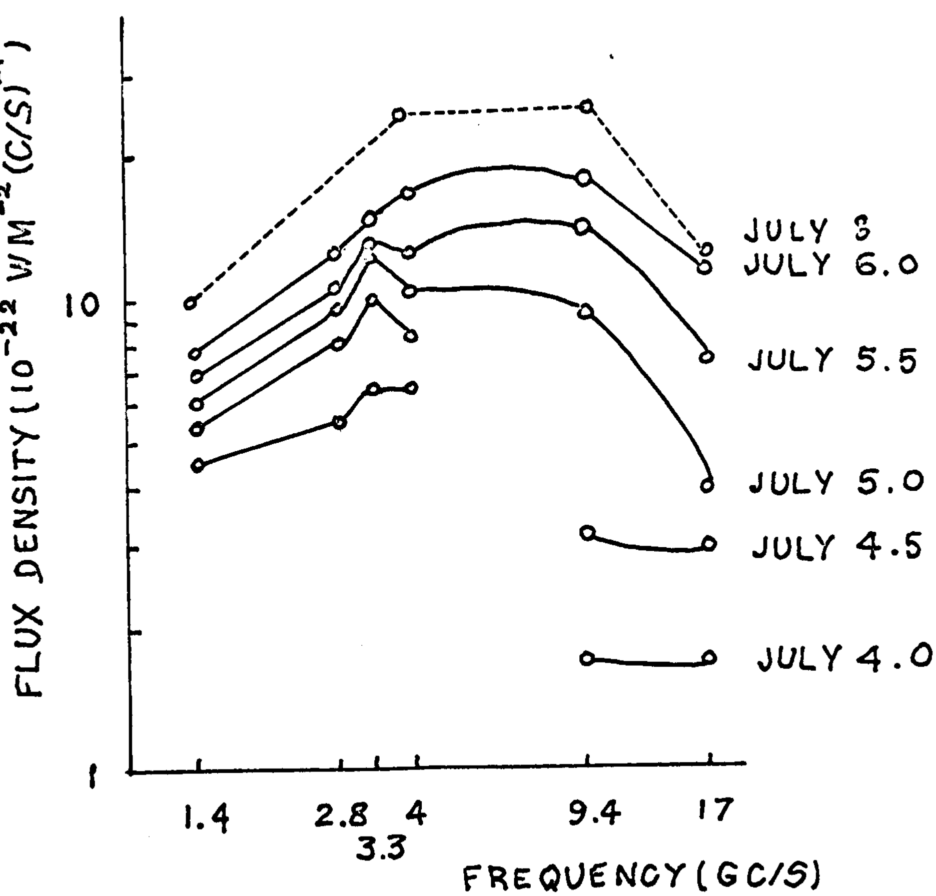
06 JUL 1966

fig 7(2)



21 cm SYDNEY
10.7 OTTAWA
9.1 STANFORD
7.5 TOYOKAWA
3.2 NANÇAY
3.2 TOYOKAWA
1.7 MITAKA
FLUX DENSITY (10^{-22} Wm^{-2}(c/s)$^{-1}$)
40
30
20
10
3
4
5
6
7
8
9
10
11
12
13
JULY 1966

fig. 8



FLUX DENSITY (10^{-22} W/M^{-2} (C/S)$^{-1}$)
10
1
1.4
2.8
3.3
4
9.4
17
FREQUENCY (GC/S)
JULY 8
JULY 6.0
JULY 5.5
JULY 5.0
JULY 4.5
JULY 4.0

fig. 9

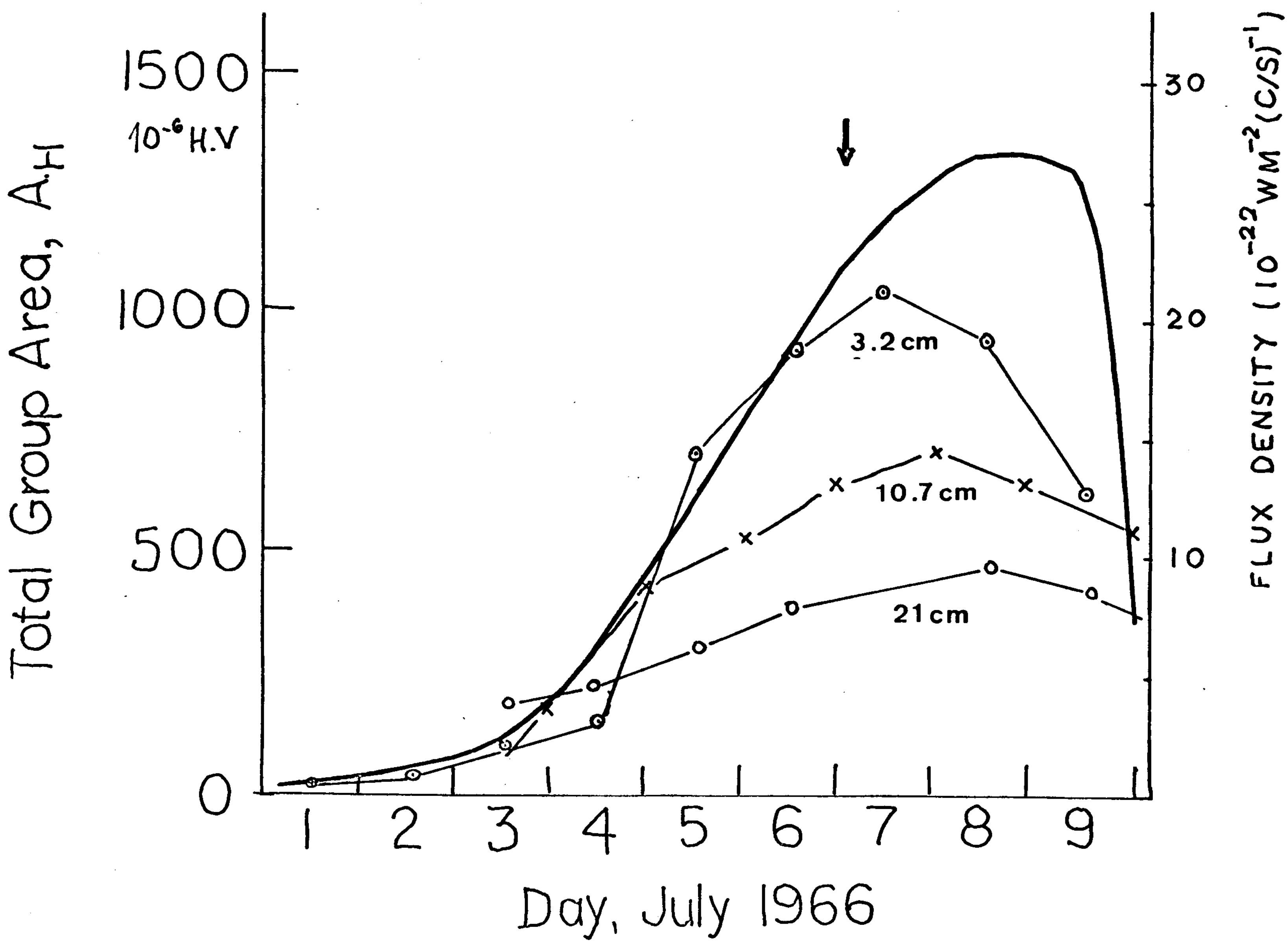

Total Group Area, A_H
10^{-6} H.V
1500
1000
500
0
FLUX DENSITY ($10^{-22} WM^{-2} (C/S)^{-1}$)
30
20
10
3.2 cm
10.7 cm
21 cm
1
2
3
4
5
6
7
8
9
Day, July 1966

fig. 10

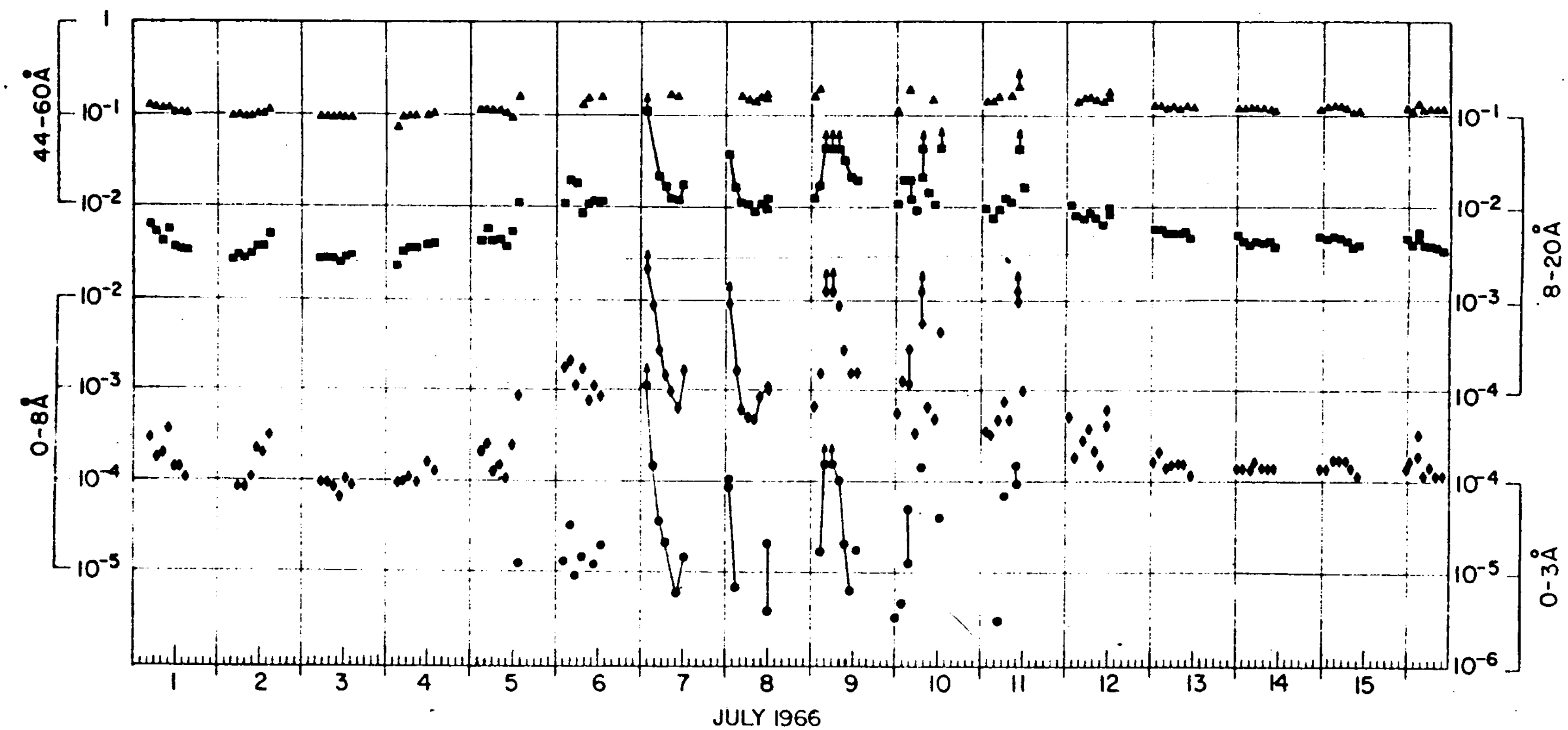

44-60Å
0-8Å
8-20Å
0-3Å
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
JULY 1966

fig 11

R E F E R E N C E S

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9 - HOWARD R. 1963, Astrophys. J., 138, 1312 - 1313.

PIONEER VI OBSERVATIONS OF THE SOLAR FLARE

PARTICLE EVENT OF 7 JULY, 1966

by

U. R. Rao

Physical Research Laboratory, Ahmedabad, India

K. G. McCracken

University of Adelaide, Australia

R. P. Bukata

Southwest Center for Advanced Studies, Dallas, Texas

ABSTRACT

The solar flare effects, and Forbush decrease occurring during the period 5-15 July, 1966, as observed by a detector on the Pioneer VI spacecraft some 45° away from earth in solar longitude, are discussed. We conclude that the phenomena observed throughout the interval are completely typical of solar flare effects: -- thus a non-equilibrium anisotropy was observed from the "garden hose" direction at early times; a bi-directional anisotropy was observed subsequent to the onset of the Forbush decrease; and a equilibrium anisotropy due to convective removal of the cosmic rays from the solar system was observed at late times during the period. We infer that the velocity of propagation of the plasma disturbance responsible for the Forbush decrease was not significantly different ($\pm$ 25%) over a range of 45° of heliographic longitude.

PIONEER VI OBSERVATIONS OF THE SOLAR FLARE PARTICLE EVENT OF 7 JULY, 1966

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1. Introduction

In this paper we present detailed information on the time dependence, the degree of anisotropy and the spectral composition of cosmic radiation generated during a series of flares which occurred during the period 5 July - 20 July, 1966, with the major flare occurring on 7 July, 1966. The observations presented here were made by a cosmic ray detector on board the Pioneer VI spacecraft which was launched into a heliocentric orbit on 16 December, 1965. During the period 5 July - 20 July, 1966, the spacecraft was at a distance of approximately 0.8 A. U. from the sun and the spacecraft-sun-earth angle was about 45°.

Detailed descriptions of the cosmic ray detector and the techniques used to study solar flares are given elsewhere (Bartley, McCracken and Rao, 1967A; McCracken, Rao and Bukata, 1967). Briefly the detector records cosmic rays from four directions for each of three energy windows of nominal energy 7.5 - 45 Mev and 150 - 350 Mev. Each directional counting rate is obtained by counting the pulses from the detector with a data accumulator as the axis of the detector sweeps out a fixed range of azimuths. The range of spacecraft azimuths corresponding to each directional counting rate is indicated on Figure 1. Since any differences in the data corresponding to the four directions will be attributed to the existence of an anisotropy in the cosmic radiation, extreme care has been taken to insure that such differences do not arise from unequal accumulation times in the different quadrants. An accuracy of better than 2.5 parts in 10^5 in the accumulation time has been achieved by using a self-calibrating, accurate time dividing circuit (Bartley, McCracken and Rao, 1967B) on board the spacecraft.

In addition to the measurement of directional counting rates described above, the integral counting rate of all particles of energy greater than 7.5 Mev is also recorded. The counting rate of this integral channel is extremely high (about 130 counts/second), and consequently we are able to record cosmic ray intensity changes with a very great statistical accuracy.

2. Data Reduction

A detailed account of the procedures employed in the data reduction is presented elsewhere (Bartley et al 1966, McCracken, Rao and Bukata, 1967). For the analysis presented in this paper, data averaged over 7.5 minutes have been employed. For each 7.5 minute interval, the four directional counting rates for each of the energy windows constitute a "snapshot" of the cosmic ray anisotropy for that particular energy channel. By fitting a sinusoid to each of the 7.5 minute snapshots, the amplitude A and the direction θ_A of the anisotropy are obtained which provide a quantitative description of the cosmic ray anisotropy.

Almost continuous data coverage is available for the periods 16 December, 1965 to 30 April, 1966, (Pioneer VI) and 17 August, 1966 - 30 November, 1966 (Pioneer VII). During the intervening period 1 May, 1966 - 17 August, 1966, the data coverage for Pioneer VI is incomplete, due to tracking limitations. In Figure 2 are plotted the available Pioneer VI data for the period 5 - 12 July, 1966, along with the Deep River neutron monitor data.

The period 5 July - 20 July was extremely disturbed insofar as interplanetary conditions were concerned. A large number of solar flares of importance greater than 2B were observed, many of which will have generated sufficient cosmic radiation to be detected by our instrument (80% of all flares of importance 2B are observed to do so). The majority of our data during this period of time were obtained after 0800 UT on July 9, at which time the cosmic ray flux was rapidly decaying as a function of time. The fact that a flare which occurred at 0022 UT on July 7 generated sufficient relativistic cosmic rays to be detected by ground based neutron monitors, suggests that the majority of the cosmic rays observed on July 9 were released by this flare. However, this identification of the actual flare responsible for the particle acceleration is of no consequence in the following discussion.

A Forbush decrease was observed at the Earth commencing at about 0000 UT on July 9, minimum intensity being observed at about 1500 UT on the same day. During the period 1200 - 1600 UT on July 9, the solar cosmic ray fluxes observed at Pioneer VI were bi-directional, as is shown in Figure 3; that is, the cosmic ray flux was showing a maximum from two directions differing by approximately 180°. We have shown that such bi-directional fluxes are invariably associated with the minimum intensity phase of a Forbush decrease (Rao, McCracken and Bukata, 1967), and therefore conclude that a Forbush decrease occurred at Pioneer VI prior to 0800 UT on July 9, and that the minimum intensity phase occurred in the vicinity of 1200 - 1600 UT. This implies that the Forbush decrease at Pioneer VI occurred simultaneously, or <u>earlier</u> than at the earth. This is consistent with the assumption that a) the Forbush decrease was due to a shock wave originating in the flare which occurred 45° west of the central solar meridian (as seen from the earth) at 0022 UT on July 7; b) that the shock wave expanded radially outwards at approximately the same velocity ($\pm$ 20%) over at least 45° of solar longitude.

Figure 4 demonstrates the manner in which the cosmic ray anisotropy varies throughout the period of interest. This diagram is essentially a vector addition diagram, each vector being of a length proportional to the amplitude of the anisotropy, and being in the "direction of flow" of the cosmic rays. The figure shows all of the phenomenological changes in the state of the anisotropy which are typically associated with solar flare and Forbush decrease events (McCracken, Rao and Bukata, 1967; Rao, McCracken and Bukata, 1967). Thus the anisotropy is of the non-equilibrium variety at early times; it becomes bi-directional soon after the onset of the Forbush decrease; and is of the "equilibrium anisotropy" variety at late times. This time sequence is very typical, and in Figure 5, we present a similar sequence of events (flare, Forbush decrease, etc.) observed in September 1966, for which greater continuity of data acquisition was achieved. This latter event serves as a useful guide in interpreting the phenomena observed during the July events.

The Non Equilibrium Anisotropy, July 5, 1967

Figure 4 shows that on July 5 the maximum cosmic ray flux arrived at the spacecraft from a direction approximately 45° west of the spacecraft-sun line. This observation is consistent with the hypothesis that the cosmic rays were streaming along the lines of force of the interplanetary magnetic field (the typical "garden hose" angle being 45° west). This behaviour is typical of the initial stages of a flare effect (See Figure 5, the commencement of the cosmic ray enhancement being at 0300 UT on September 21), in that the direction of maximum cosmic ray flux is always aligned with the interplanetary magnetic field vector (parallel, or antiparallel). This situation is indicative of a non-homogeneous distribution of cosmic radiation throughout the solar system, the cosmic radiation flowing along the magnetic lines of force in order to eliminate these inhomogeneities. It has been shown (McCracken, Rao and Ness, 1967) that the cosmic ray anisotropy direction is very strongly correlated with the magnetic field direction during the non-equilibrium anisotropy phase of a cosmic ray flare effect.

The Equilibrium Anisotropy

Figure 4 shows that on July 10 and 11, the cosmic ray anisotropy was such that the maximum flux was always from the general direction of the sun. A similar behaviour is evident in Figure 5 after 0500 UT on 25 September, and we find that anisotropies such as these, exhibiting time invariant amplitudes and phases, are commonly observed at late times during a solar flare effect. This species of anisotropy is normally associated with the decay phase of the flare effect, when the cosmic ray flux is monotonically decreasing with time. It has been suggested (McCracken, Rao and Bukata, 1967) that the equilibrium anisotropy is an indicator of the cosmic radiation being in diffusive equilibrium in the portion of the solar system accessible (magnetically) to the spacecraft.

The mechanism advanced to explain the equilibrium anisotropy (Rao, McCracken and Bukata, 1967) is that the cosmic radiation is essentially uniformly distributed throughout the solar system, and that it is being swept radially outwards by the solar wind. The cosmic ray population is therefore moving with a bulk velocity of V_P (the plasma velocity), and consequently an observer in a stationary frame of reference will see an anisotropy of amplitude $(3 + \beta)\ V_P/V$ (Compton and Getting, 1938), where V is cosmic ray particle velocity, and is the exponent of the differential energy spectrum which varies as $E^{-\beta}$. Comparison of the 7.5 - 45 Mev and 45 - 90 Mev Pioneer VI data for July 11 indicates a spectrum varying as $E^{-3.8}$, and this, along with the mean value of 18% for the anisotropy on July 11, indicates a solar wind velocity of $\sim$1100 km/sec.

Conclusions

We conclude that the cosmic ray flare effects observed during 5 July - 15 July were completely typical of other solar flare effects observed during 1965 - 1966 by the Pioneer VI and VII spacecrafts. In particular, the period in question exhibited non-equilibrium (field aligned) anisotropies at early times, followed by bi-directional anisotropies during the minimum of the Forbush decrease on July 9th, and equilibrium (convective removal) anisotropies thereafter. The cosmic ray anisotropy data indicate that the interplanetary magnetic field was of the typical "Archimedes Spiral" configuration on July 5, and that the solar wind velocity was approximately 1100 km/sec on July 11. The approximately simultaneous onset of a large Forbush decrease at the spacecraft, and earth, on July 9 indicates approximate equality of the plasma disturbance propagation velocity over a range of about 45^{o} in solar longitude.

ACKNOWLEDGEMENTS

The cosmic ray detector was developed at the Southwest Center for Advanced Studies, Dallas, Texas. The research was supported by the National Aeronautics and Space Administration under contracts NAS2-1756 and NSR-44-004-043, by a grant from the Indian Atomic Energy Commission and by funds provided by the Australian Research Grants Committee. The authors are grateful to Mr. W. C. Bartley for help of many kinds during the development, construction and integration of the detector.

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CAPTIONS

Figure 1 — The range of directions swept out by the axis of symmetry of the Pioneer cosmic ray anisotropy detector for each quadrant is indicated, along with the mean direction of viewing of each quadrant (the heavy arrows). This diagram is as seen from the North ecliptic pole. The shaded sectors are the directions swept out in the Enhanced Dynamic Range mode of operation.

Figure 2 — The time profile of the cosmic ray intensity of energy greater than 7.5 Mev during the period 5 - 12 July, 1966 is plotted along with the hourly counting rate as observed by the Deep River neutron monitor. The typical features observed in the solar flare are indicated in the diagram.

Figure 3 — Anisotropy snapshots of the cosmic ray flux during the transition from unidirectional anisotropy to bidirectional anisotropy at the time of the minimum intensity phase of the Forbush decrease. The subsequent conversion to unidirectional anisotropy is also shown.

Figure 4 — The amplitude and azimuth of the cosmic ray anisotropy (7.5 - 45 Mev) plotted as a vector addition diagram for the period 5 - 12 July, 1966. Notice the long persistent anisotropy of mean amplitude $\approx$ 18.0% which commenced at 0900 UT on July 11, 1966.

Figure 5 — The anisotropy vector diagram for the period September 21 - September 25, 1966. The typical two step profile of the Forbush decrease indicated in the diagram is discussed elsewhere (Rao, McCracken and Bukata, 1967).

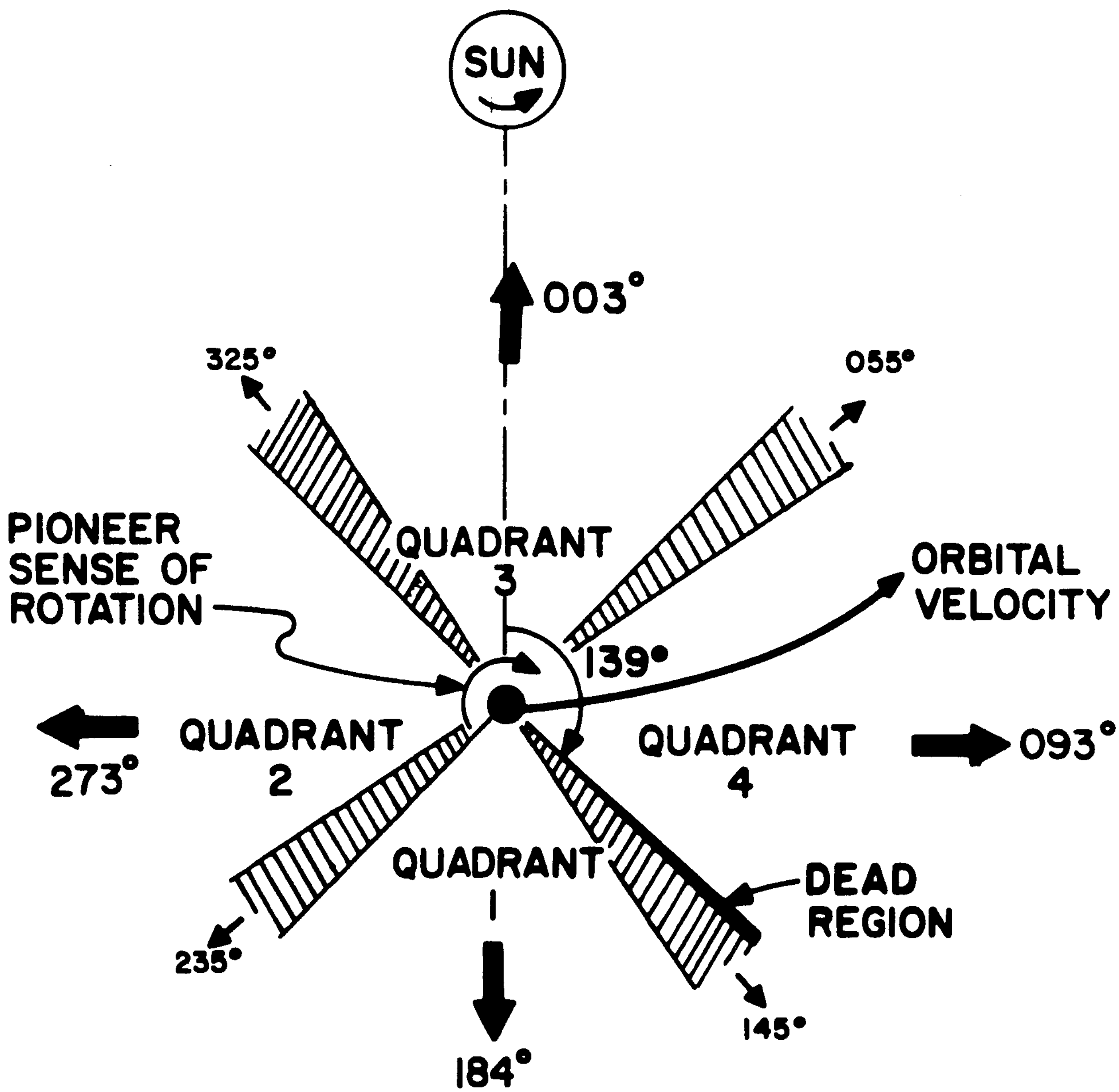
SUN
003°
325°
055°
PIONEER
SENSE OF
ROTATION
QUADRANT
3
ORBITAL
VELOCITY
139°
273°
QUADRANT
2
QUADRANT
4
093°
QUADRANT
1
DEAD
REGION
235°
145°
184°

FIGURE 1.

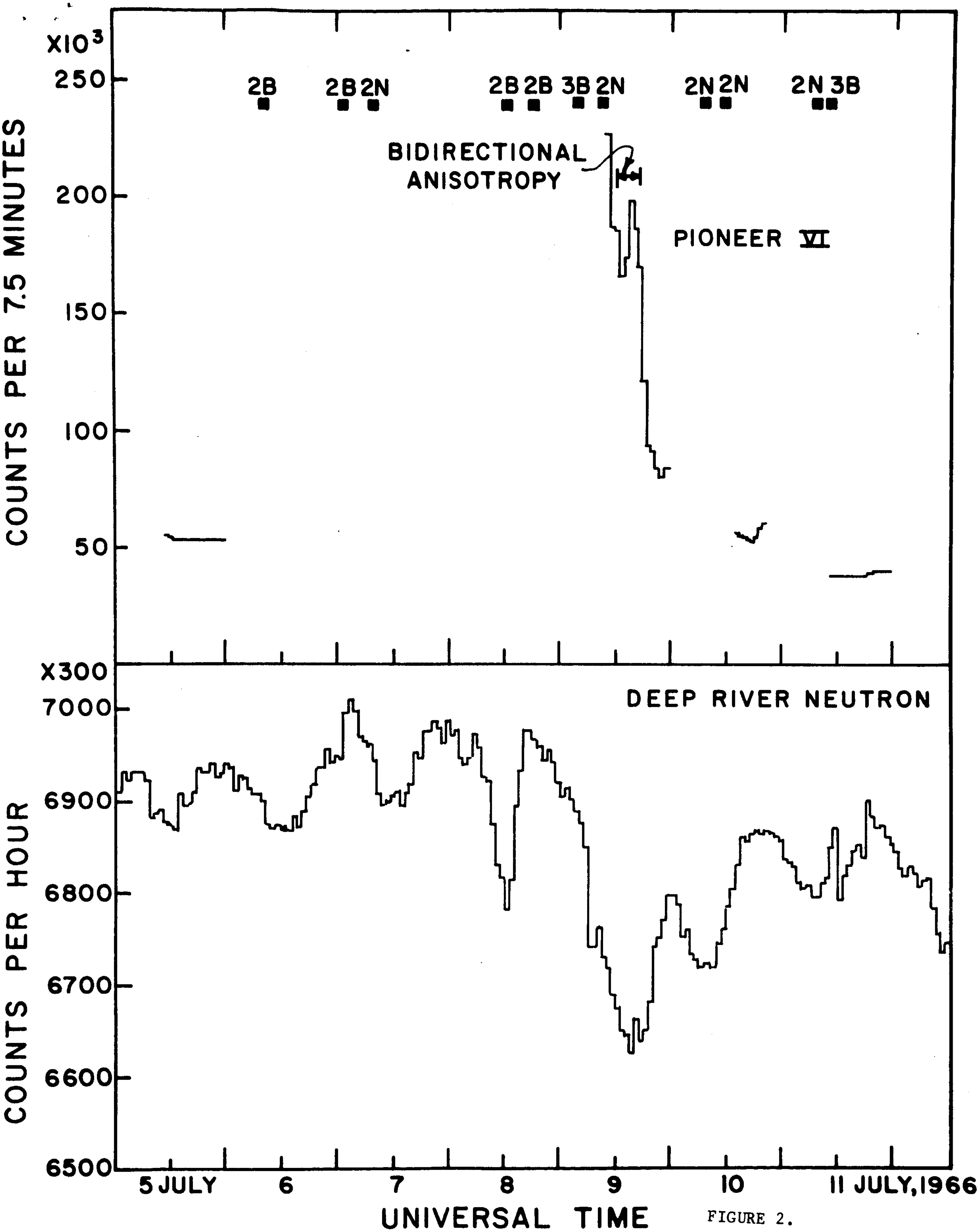
X10³
250
200
150
100
50
2B
2B 2N
2B 2B 3B 2N
2N 2N
2N 3B
BIDIRECTIONAL
ANISOTROPY
PIONEER VI
COUNTS PER 7.5 MINUTES
X300
7000
6900
6800
6700
6600
6500
DEEP RIVER NEUTRON
COUNTS PER HOUR
5 JULY
6
7
8
9
10
11 JULY, 1966
UNIVERSAL TIME

FIGURE 2.

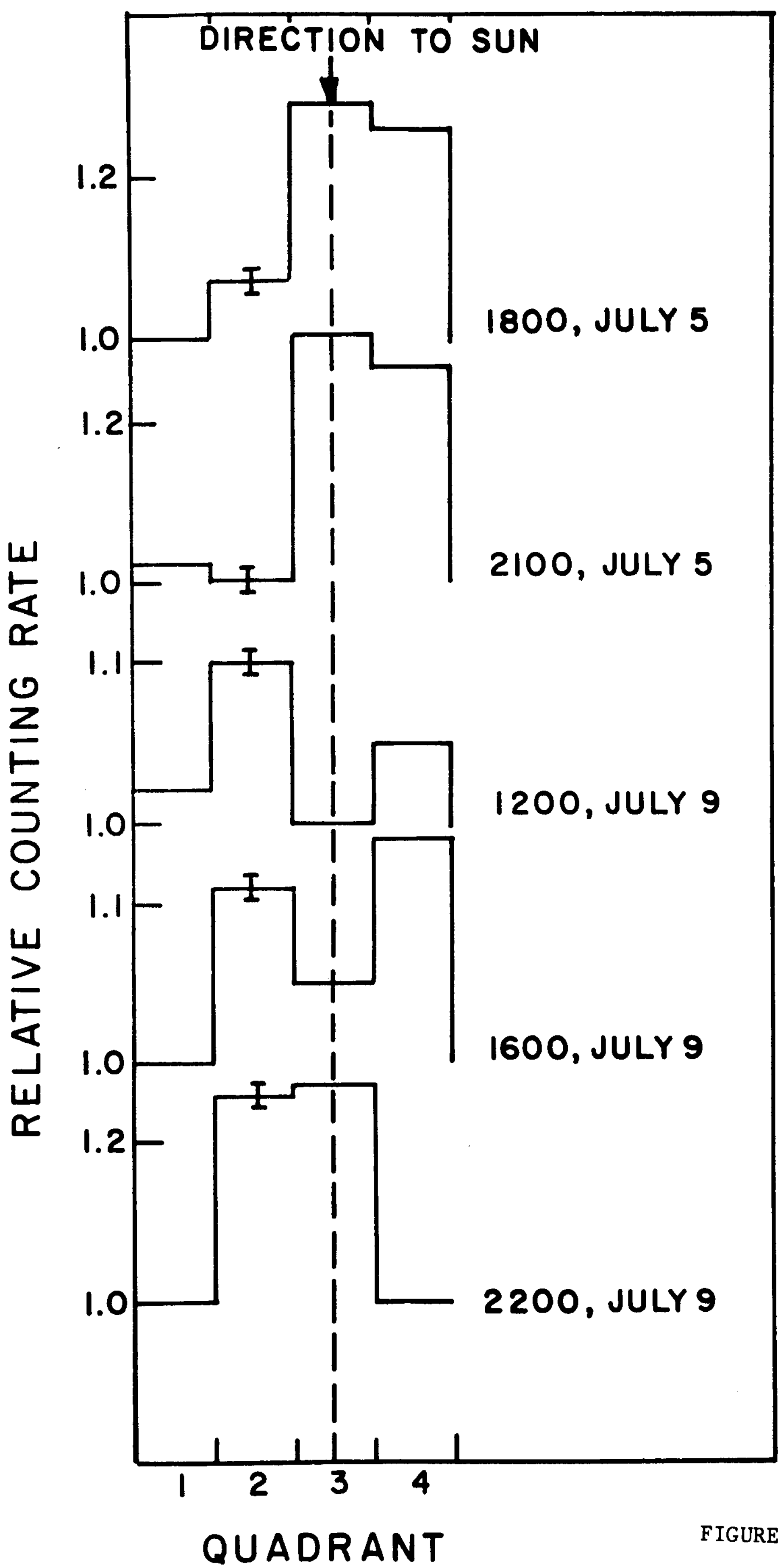
DIRECTION TO SUN
1.2
1.0
1800, JULY 5
1.2
1.0
2100, JULY 5
1.1
1.0
1200, JULY 9
1.1
1.0
1600, JULY 9
1.2
1.0
2200, JULY 9
RELATIVE COUNTING RATE
1
2
3
4
QUADRANT

FIGURE 3.

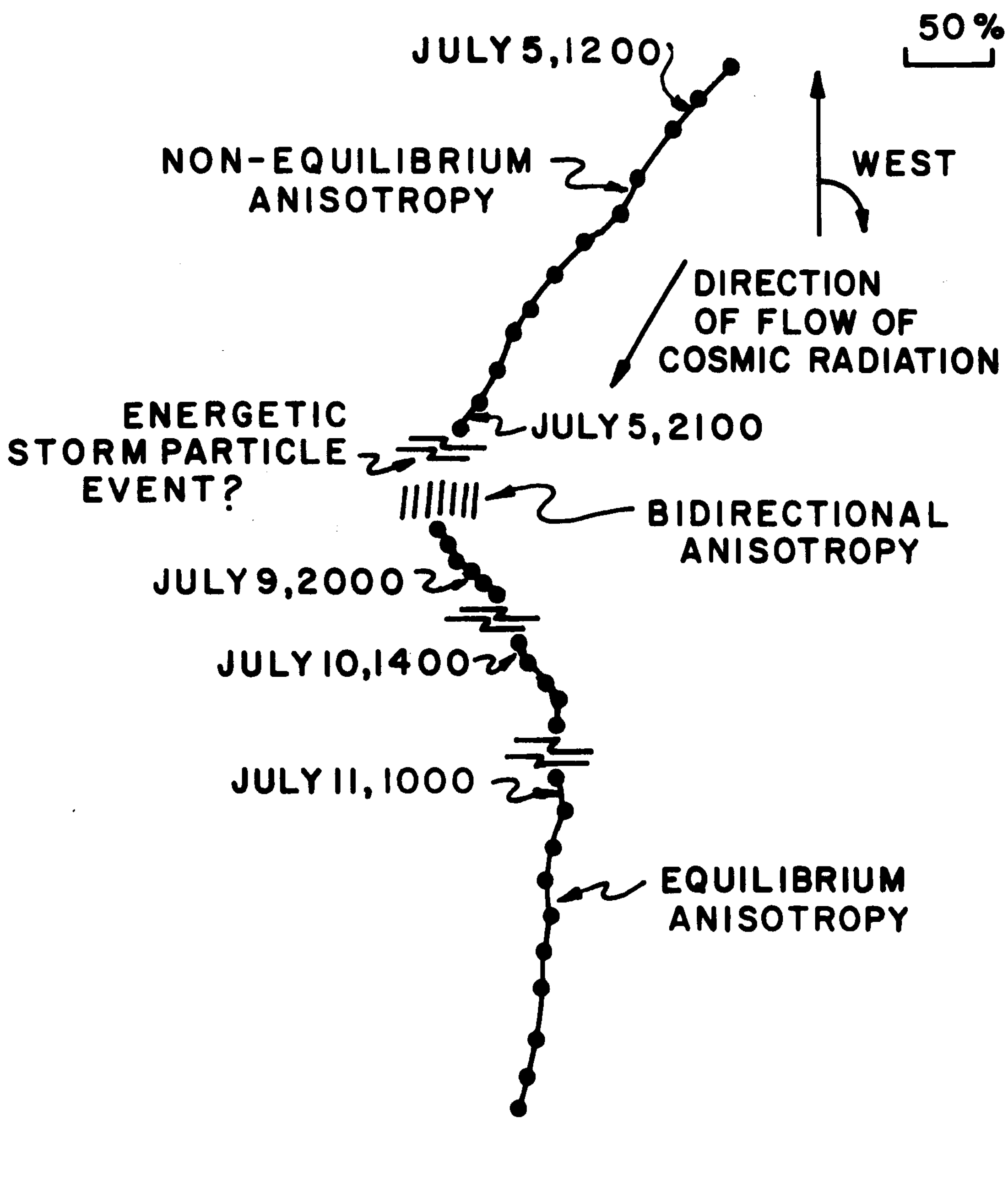
JULY 5,1200
50 %
NON-EQUILIBRIUM ANISOTROPY
WEST
DIRECTION OF FLOW OF COSMIC RADIATION
ENERGETIC STORM PARTICLE EVENT?
JULY 5,2100
BIDIRECTIONAL ANISOTROPY
JULY 9,2000
JULY 10,1400
JULY 11,1000
EQUILIBRIUM ANISOTROPY

FIGURE 4.

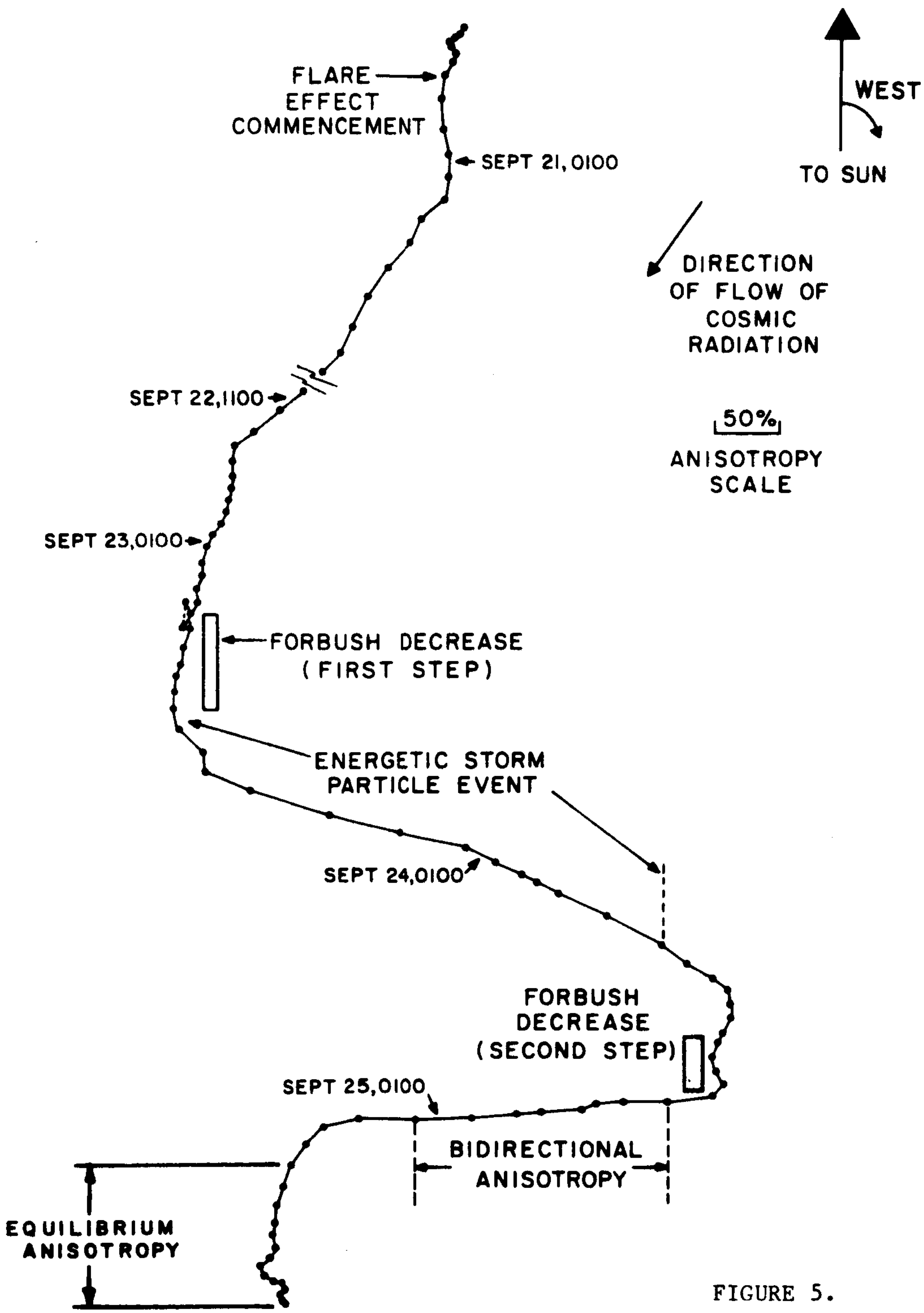
FLARE EFFECT COMMENCEMENT
SEPT 21, 0100
SEPT 22,1100
SEPT 23,0100
FORBUSH DECREASE (FIRST STEP)
ENERGETIC STORM PARTICLE EVENT
SEPT 24,0100
FORBUSH DECREASE (SECOND STEP)
SEPT 25,0100
BIDIRECTIONAL ANISOTROPY
EQUILIBRIUM ANISOTROPY
WEST
TO SUN
DIRECTION OF FLOW OF COSMIC RADIATION
50%
ANISOTROPY SCALE

FIGURE 5.